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DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 13

BOUNDARIES OF THE UNITED STATES AND OF THE SEVERAL
STATES AND TERRITORIES, WITH A HISTORICAL
SKETCH OF THE TERRITORIAL CHANGES

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

ADVERTISEMENT.

[Bulletin No. 12.]

The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed in addition to the number in each case stated, the 'usual number' (1,000) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,000 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 70 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. 1 v. 568 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xli, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

MONOGRAPHS

So far as already determined upon, the list of the Monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. Published.

IV. Comstock Mining and Minerals, by Elliot Lord. Published.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. Published.

VI. Older Mesozoic Flora of Virginia, by Prof. William M. Fontaine. Published.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. Published.

VIII. Paleontology of the Eureka District, Nevada, by Charles D. Walcott. In press.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greens and Marls of New Jersey, by R. P. Whitfield. In press.

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- Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. In preparation.
 Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague. In preparation.
 Lake Bonneville, by G. K. Gilbert. In preparation.
 Dinocerata. A Monograph on an extinct order of Ungulates, by Prof. O. C. Marsh. In preparation.
 Saurpoda, by Prof. O. C. Marsh. In preparation.
 Stegosauria, by Prof. O. C. Marsh. In preparation.
 Of these Monographs, Nos. II, III, IV, V, VI, and VII are now published, viz:
 II. Tertiary History of the Grand Cañon District, with atlas, by C. E. Dutton, Capt., U. S. A. 1882.
 4°. 264 pp. 42 pl. and atlas of 26 double sheets folio. Price \$10.12.
 III. Geology of the Comstock Lode and Washoe District, with atlas, by G. F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price \$11.
 IV. Comstock Mining and Minerals, by Elliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price \$1.50.
 V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. 1883. 4°. xvi, 464 pp. 29 pl. Price \$1.85.
 VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by William M. Fontaine. 1883. 4°. xix, 128 pp. 54 l. 54 pl. Price \$1.05.
 VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xii, 200 pp. 15 pl. Price \$1.20.
 Nos. VIII and IX are in press and will soon appear. The others, to which numbers are not assigned, are in preparation.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins, Nos. 1 to 13 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augittite Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.
2. Gold and Silver Conversion Tables, giving the coinage value of Troy ounces of fine metal, &c., by Albert Williams, Jr. 1883. 8°. ii, 8 pp. Price 5 cents.
3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30', from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.
4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.
5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.
6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.
7. *Mapoteca Geologica Americana*. A catalogue of geological maps of America (North and South), 1752-1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.
8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. Price 10 cents.
9. A Report of the Work Done in the Washington Laboratory during the fiscal year 1883-'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.
10. On the Cambrian Faunas of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8°. 74 pp. Price 5 cents.
11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. Price 5 cents.
12. A Crystallographic Study of the Thimolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 24 pp. Price 5 cents.
13. Boundaries of the United States and of the several States and Territories, with a historical sketch of the territorial changes, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

STATISTICAL PAPERS.

A fourth series of publications having special reference to the mineral resources of the United States is contemplated. Of that series the first has been published, viz: *Mineral Resources of the United States*, by Albert Williams, Jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

The second volume of this series, *Mineral Statistics 1883 and 1884*, is in preparation and will soon be put to press.

Correspondence relating to the publications of the Survey, and all remittances, which must be by postal note or money order, should be addressed to the

DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY,

Washington, D. C.

WASHINGTON, D. C., January 15, 1885.

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 13



WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

BOUNDARIES
OF
THE UNITED STATES

AND OF THE
SEVERAL STATES AND TERRITORIES

WITH A
HISTORICAL SKETCH OF THE TERRITORIAL CHANGES

BY
HENRY GANNETT
CHIEF GEOGRAPHER



WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., October 16, 1884.

SIR: I have the honor to submit herewith a sketch of the boundaries of the United States, the several States, and the Territories, as defined by treaty, charter, or statute.

Besides giving the present status of these boundaries, I have endeavored to present an outline of the history of all important changes of territory, with the laws appertaining thereto.

This matter was in great part prepared under the direction of the Superintendent of the Census, and it is herewith presented for publication with his full concurrence.

I have been greatly assisted in this work by Mr. Franklin G. Butterfield, who was formerly connected with the Census Office, by whose labors most of the material relating to the boundaries of the States upon the Atlantic borders has been compiled.

Very respectfully, yours,

HENRY GANNETT,
Chief Geographer.

Hon. J. W. POWELL,
Director.

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CHAPTER I.

BOUNDARIES OF THE UNITED STATES, AND ADDITIONS TO ITS TERRITORY.

BOUNDARIES OF THE UNITED STATES.

The limits of the United States were first definitely laid down in the provisional treaty made with Great Britain in 1782. The second article of that treaty defines the boundary between the United States on the one hand and the British Possessions on the other, as follows:

From the northwest angle of Nova Scotia, viz, that angle which is formed by a line drawn due north from the source of St. Croix river to the highlands; along the High-lands which divide those rivers that empty themselves into the river St. Lawrence, from those which fall into the Atlantic Ocean, to the northwesternmost head of Connecticut River; thence down along the middle of that river to the forty-fifth degree of north latitude; from thence, by a line due west on said latitude until it strikes the river Iroquois or Cataraquy (St. Lawrence); thence along the middle of said river into Lake Ontario, through the middle of said lake until it strikes the communication by water between that lake and Lake Erie; thence along the middle of said communication into Lake Erie, through the middle of said lake until it arrives at the water communication between that lake and Lake Huron; thence along the middle of said water communication into the Lake Huron; thence through the middle of said lake to the water communication between that lake and Lake Superior; thence through Lake Superior northward of the Isles Royal and Phelippeaux to the Long Lake; thence through the middle of said Long Lake, and the water communication between it and the Lake of the Woods, to the said Lake of the Woods; thence through the said lake, to the most northwestern point thereof, and from thence on a due west course to the river Mississippi; thence by a line to be drawn along the middle of the said river Mississippi until it shall intersect the northernmost part of the thirty-first degree of north latitude. South by a line to be drawn due east from the determination of the line last mentioned, in the latitude of thirty-one degrees north of the Equator, to the middle of the river Apalachicola or Catahouche; thence along the middle thereof to its junction with the Flint River; thence strait to the head of St. Mary's River; and thence down along the middle of St. Mary's River to the Atlantic Ocean. East by a line to be drawn along the middle of the river St. Croix, from its mouth in the Bay of Fundy to its source, and from its source directly north to the aforesaid highlands which divide the rivers that fall into the Atlantic Ocean from those which fall into the river St. Lawrence; comprehending all islands within twenty leagues of any part of the shores of the United States, and lying between lines to be drawn due east from the points where the aforesaid boundaries between Nova Scotia on the one part and East Florida on the other, shall respectively touch the Bay of Fundy and the Atlantic Ocean; excepting such islands as now are, or heretofore have been within the limits of the said province of Nova Scotia.

The boundary between the United States and the Spanish Possessions, known as the Floridas, is reaffirmed in the treaty between the United States and Spain, made in 1795, in the following terms :

The southern boundary of the United States, which divides their territory from the Spanish colonies of East and West Florida, shall be designated by a line beginning on the river Mississippi, at the northernmost part of the thirty-first degree of latitude north of the equator, which from thence shall be drawn due east to the middle of the river Apalachicola or Catahouche, thence along the middle thereof to its junction with the Flint; thence straight to the head of St. Mary's River, and thence down the middle thereof to the Atlantic Ocean.

The definitive treaty of peace with Great Britain, concluded September 3, 1783, defines the boundaries of the United States in terms similar to those of the provisional treaty.

The northern boundary became at once a fruitful source of dissension between the two countries. From the time of the conclusion of peace almost up to the present day this line has been the subject of a series of treaties, commissions, and surveys for the purpose of interpreting its terms.

The following is in outline a history of the settlement of this boundary :

The fourth article of the treaty of London, signed November 19, 1794, provided that—

Whereas it is uncertain whether the river Mississippi extends so far to the northward as to be intersected by a line to be drawn due west from the Lake of the Woods in the manner mentioned in the treaty of peace between His Majesty and the United States, etc., the two parties will proceed by amicable negotiation to regulate the boundary line in that quarter.

This matter was not settled, however, until 1818.

The fifth article of the same treaty makes provision for settling another doubtful point, as follows :

Whereas doubts have arisen what river was truly intended under the name of the river St. Croix mentioned in the said treaty of peace, and forming a part of the boundary therein described, that question shall be referred to the final decision of commissions to be appointed in the following manner, viz.

Here follow provisions that His Majesty and the President of the United States should each appoint a commissioner, and that these two commissioners should agree on a third, or, they failing to agree on the third, he was to be chosen by lot in their presence.

Which was the true St. Croix River had been a matter of controversy between the governments of Massachusetts and Nova Scotia since the year 1764.

The commissioners appointed under the foregoing provisions decided, on the 25th October, 1798, the river called Schoodiac and the northern branch thereof (called Cheputnaticook) to be the true river St. Croix, and that its source was at the northernmost headspring of the northern branch aforesaid. A monument was erected at that spot under the direction of the commissioners. (See *Memoirs of Northeastern Boundary*, Gallatin, pages 7, 8)

By the treaty of peace concluded at Ghent, December 24, 1814, it was agreed to provide for a final adjustment of the boundaries described in the treaty of 1783, which had not yet been ascertained and determined, embracing certain islands in the Bay of Fundy and the whole of the boundary line from the source of the river St Croix to the most north-western point of the Lake of the Woods.

By article 4 provision was made for a board of commissioners to settle the title to several islands in the Bay of Passamaquoddy, which is a part of the Bay of Fundy, and the island of Grand Menan in the said Bay of Fundy.

The fifth article made provision for a board of commissioners to settle the boundary from the source of the river St. Croix northward to the highland which divides those waters that empty themselves into the river St. Lawrence from those which fall into the Atlantic Ocean, thence along said highlands to the northwesternmost head of Connecticut River, thence down along the middle of that river to the forty-fifth degree of north latitude, thence due west on said latitude until it strikes the river Iroquois or Cataraguy (St. Lawrence).

The sixth and seventh articles provided for commissioners to continue the line to the northwestern point of the Lake of the Woods.

(For further details see treaty, Statutes at Large, vol. 8, pages 220-2.)

It was provided by this treaty that in case any of the boards of commissioners were unable to agree, they should make separately or jointly a report or reports to their respective Governments stating the points on which they differed, the grounds on which they based their respective opinions, etc.

These reports were to be referred to some friendly sovereign or state for arbitration.

The first and third boards of commissioners above mentioned came to an agreement, and those portions of the boundary were thus finally settled; but the commission appointed under the fifth article, after sitting nearly five years, could not agree on any of the matters referred to them, nor even on a general map of the country exhibiting the boundaries respectively claimed by each party. They accordingly made separate reports to their Governments, stating the points on which they differed and the grounds upon which their respective opinions had been formed.

The first of these commissions awarded Moore, Dudley, and Frederick Islands to the United States, and all other islands in the Passamaquoddy Bay, and the island of Grand Menan, to Great Britain.

The following is the text of the report of the third of these commissions which had under consideration that portion of the northern boundary between the point where the forty-fifth parallel of north latitude strikes the St. Lawrence and the point where the boundary reaches Lake Superior:

Decision of the commissioners under the sixth article of the treaty of Ghent, done at Utica, in the State of New York, 18th June, 1822.

We do decide and declare that the following-described line (which is more clearly indicated on a series of maps accompanying this report, exhibiting correct surveys and delineations of all the rivers, lakes, water communications, and islands embraced by the sixth article of the treaty of Ghent, by a black line shaded on the British side with red and on the American side with blue; and each sheet of which series of maps is identified by a certificate, subscribed by the commissioners, and by the two principal surveyors employed by them) is the true boundary intended by the two beforementioned treaties, that is to say:

Beginning at a stone monument, erected by Andrew Ellicot, esq., in the year 1817, on the south bank or shore of the said river Iroquois, or Cataraqui (now called the St. Lawrence), which monument bears south $74^{\circ} 45'$ west, and is 1,840 yards distant from the stone church in the Indian village of St. Regis, and indicates the point at which the forty-fifth parallel of north latitude strikes the said river; thence running north $35^{\circ} 45'$ west into the river, on a line at right angles with the southern shore, to a point 100 yards south of the opposite island, called Cornwall Island; thence turning westerly and passing around the southern and western sides of said island, keeping 100 yards distant therefrom, and following the curvatures of its shores, to a point opposite to the northwest corner or angle of said island; thence to and along the middle of the main river until it approaches the eastern extremity of Barnhart's Island; thence northerly along the channel which divides the last-mentioned island from the Canada shore, keeping 100 yards distant from the island, until it approaches Sheik's Island; thence along the middle of the strait which divides Barnhart's and Sheik's Islands to the channel called the Long Sault, which separates the two last-mentioned islands from the lower Long Sault Island; thence westerly (crossing the center of the last-mentioned channel) until it approaches within 100 yards of the north shore of the Lower Sault Island; thence up the north branch of the river, keeping to the north of and near the Lower Sault Island, and also north of and near the Upper Sault, sometimes called Baxter's Island, and south of the two small islands marked on the map A and B, to the western extremity of the Upper Sault or Baxter's Island; thence, passing between the two islands called the Cats, to the middle of the river above; thence along the middle of the river, keeping to the north of the small islands marked C and D, and north also of Chrysler's Island, and of the small island next above it, marked E, until it approaches the northeast angle of Goose Neck Island; thence along the passage which divides the last-mentioned island from the Canada shore, keeping 100 yards from the island to the upper end of the same; thence south of and near the two small islands called the Nut Islands; thence north of and near the island marked F, and also of the island called Dry or Smuggler's Island; thence passing between the islands marked G and H to the north of the island called Isle au Rapid Platt; thence along the north side of the last-mentioned island, keeping 100 yards from the shore, to the upper end thereof; thence along the middle of the river, keeping to the south of and near the islands called Cousin (or Tussin) and Presque Isle; thence up the river, keeping north of and near the several Gallop Isles numbered on the map 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10, and also of Tick, Tibbits, and Chimney Islands, and south of and near the Gallop Isles numbered 11, 12, and 13, and also of Duck, Drummond, and Sheep Islands; thence along the middle of the river, passing north of island No. 14, south of 15 and 16, north of 17, south of 18, 19, 20, 21, 22, 23, 24, 25, and 28, and north of 26 and 27; thence along the middle of the river, north of Gull Island and of the islands Nos. 29, 32, 33, 34, 35, Bluff Island, and Nos. 39, 44, and 45, and to the south of Nos. 30, 31, 36, Grenadier Island, and Nos. 37, 38, 40, 41, 42, 43, 46, 47, and 48, until it approaches the east end of Well's Island; thence to the north of Well's Island, and along the strait which divides it

from Rowe's Island, keeping to the north of the small islands Nos. 51, 52, 54, 58, 59, and 61, and to the south of the small islands numbered and marked 49, 50, 53, 55, 57, 60, and H, until it approaches the northeast point of Grindstone Island; thence to the north of Grindstone Island, and keeping to the north also of the small islands Nos. 63, 65, 67, 68, 70, 72, 73, 74, 75, 76, 77, and 78, and to the south of Nos. 62, 64, 66, 69, and 71, until it approaches the southern point of Hickory Island; thence passing to the south of Hickory Island and of the two small islands lying near its southern extremity, numbered 79 and 80; thence to the south of Grand or Long Island, keeping near its southern shore, and passing to the north of Carlton Island, until it arrives opposite to the southwestern point of said Grand Island, in Lake Ontario; thence, passing to the north of Grenadier, Fox, Stony, and the Gallop Islands, in Lake Ontario, and to the south of and near the islands called the Ducks, to the middle of the said lake; thence westerly along the middle of said lake to a point opposite the mouth of the Niagara River; thence to and up the middle of the said river to the Great Falls; thence up the Falls through the point of the Horse Shoe, keeping to the west of Iris or Goat Island, and of the group of small islands at its head, and following the bends of the river so as to enter the strait between Navy and Grand Islands; thence along the middle of said strait to the head of Navy Island; thence to the west and south of and near to Grand and Beaver Islands, and to the west of Strawberry, Squaw, and Bird Islands to Lake Erie; thence southerly and westerly along the middle of Lake Erie in a direction to enter the passage immediately south of Middle Island, being one of the easternmost of the group of islands lying in the western part of said lake; thence along the said passage, proceeding to the north of Cunningham's Island, of the three Bass Islands, and of the Western Sister, and to the south of the islands called the Hen and Chickens, and of the Eastern and Middle Sisters; thence to the middle of the mouth of the Detroit River in a direction to enter the channel which divides Bois Blanc and Sugar Islands; thence up the said channel to the west of Bois Blanc Island, and to the east of Sugar, Fox, and Stony Islands, until it approaches Fighting or Great Turkey Island; thence along the western side and near the shore of said last-mentioned island to the middle of the river above the same; thence along the middle of said river, keeping to the southeast of and near Hog Island, and to the northwest of and near the island Isle à la Pêche, to Lake Saint Clair; thence through the middle of said lake in a direction to enter that mouth or channel of the river St. Clair, which is usually denominated the Old Ship Channel; thence along the middle of said channel, between Squirrel Island on the southeast and Herson's Island on the northwest, to the upper end of the last-mentioned island, which is nearly opposite to Point au Chêne, on the American shore; thence along the middle of the river Saint Clair, keeping to the west of and near the islands called Belle Rivière Isle and the Isle aux Cerfs, to Lake Huron; thence through the middle of Lake Huron in a direction to enter the strait or passage between Drummond's Island on the west and the Little Manitou Island on the east; thence through the middle of the passage which divides the two last-mentioned islands; thence, turning northerly and westerly, around the eastern and northern shores of Drummond's Island, and proceeding in a direction to enter the passage between the island of Saint Joseph's and the American shore, passing to the north of the intermediate islands Nos. 61, 11, 10, 12, 9, 6, 4, and 2, and to the south of those numbered 15, 13, 5, and 1; thence up the said last-mentioned passage, keeping near to the island Saint Joseph's, and passing to the north and east of Isle à la Crosse and of the small islands numbered 16, 17, 18, 19, and 20, and to the south and west of those numbered 21, 22, and 23, until it strikes a line (drawn on the map with black ink and shaded on one side of the point of intersection with blue and on the other with red) passing across the river at the head of Saint Joseph's Island and at the foot of the Neebish Rapids, which line denotes the termination of the boundary directed to be run by the sixth article of the treaty of Ghent.

And the said commissioners do further decide and declare that all the islands lying

in the rivers, lakes, and water communications between the before-described boundary line and the adjacent shores of Upper Canada do, and each of them does, belong to His Britannic Majesty, and that all the islands lying in the rivers, lakes, and water communications between the said boundary line and the adjacent shores of the United States or their territories do, and each of them does, belong to the United States of America, in conformity with the true intent of the second article of the said treaty of 1783, and of the sixth article of the treaty of Ghent.

By the second article of the convention with Great Britain—1818—the boundary line was extended westward along the forty-ninth parallel of latitude to the “Stony” (Rocky) Mountains, while beyond these mountains the treaty provided that the country should remain open to both parties. The terms of the treaty are as follows:

ARTICLE 2. It is agreed that a line drawn from the most northwestern point of the Lake of the Woods along the forty-ninth parallel of north latitude, or if the said point shall not be in the forty-ninth parallel of north latitude, then that a line drawn from the said point due north or south, as the case may be, until the said line shall intersect the said parallel of north latitude, and from the point of such intersection due west along and with the said parallel, shall be the line of demarkation between the territories of the United States and those of His Britannic Majesty, and that the said line shall form the northern boundary of the said territories of the United States and the southern boundary of the territories of His Britannic Majesty from the Lake of the Woods to the Stony Mountains.

ARTICLE 3. It is agreed that any country that may be claimed by either party on the northwest coast of America, westward of the Stony Mountains, shall, together with its harbours, bays, and creeks, and the navigation of all rivers within the same, be free and open, for the term of ten years from the date of the signature of the present convention, to the vessels, citizens, and subjects of the two powers; it being well understood that this agreement is not to be construed to the prejudice of any claim which either of the two high contracting parties may have to any part of the said country, nor shall it be taken to affect the claims of any other power or state to any part of the said country; the only object of the high contracting parties in that respect being to prevent disputes and differences amongst themselves.

In 1824 negotiations were resumed between the two countries for the settlement, among other things, of the boundary west of the Rocky Mountains, but no conclusion was reached; the claim of the English Government being that the boundary line should follow the forty-ninth parallel westward to the point where this parallel strikes the great northwestern branch of the Columbia River, thence down the middle of that river to the Pacific Ocean.

In 1826 negotiations were resumed, and several compromises were proposed by both parties, but without satisfactory results. After this the whole matter remained in abeyance until the special mission of Lord Ashburton to this country in 1842.

Meanwhile the unsettled questions regarding the northeastern boundary again came up.

The case having reached that stage at which it became necessary to refer the points of difference to a friendly sovereign or state, the two powers found it expedient to regulate the proceedings and make provisions in relation to such reference, and on the 29th September, 1827, concluded a convention to that effect.

The respective claims of the United States and Great Britain were as follows, viz :

Boundary claimed by United States.—From the source of the river St. Croix (a point of departure mutually acknowledged) the boundary should be a due north line for about 140 miles, crossing the river St. John at about 75 miles. At about 97 miles it reaches a ridge or highland which divides tributary streams of the river St. John, which falls into the Bay of Fundy, from the waters of the river Ristigouche, which falls through the Bay des Chaleurs into the Gulf of St. Lawrence. In its further course the said due north line, after crossing several upper branches of the river Ristigouche, reaches, at about 140 miles, the highlands which divide the waters of the said river Ristigouche from the tributary streams of the river Metis, which falls into the river St. Lawrence.

Thence the line should run westerly and southwesterly along the highlands which divide the sources of the several rivers (from the Metis to the St. Francis) that empty themselves into the river St. Lawrence—from the sources of the tributaries of the rivers Ristigouche, St. John, Penobscot, Kennebec, and Connecticut, all which either mediately or immediately fall into the Atlantic Ocean.

Boundary claimed by Great Britain.—From the source of the river St. Croix the boundary should be a due north line about 40 miles to a point at or near Mars Hill; thence it should run westerly about 115 miles along the highlands that divide the sources of the tributaries of the river St. John from the sources of the river Penobscot to a spot called Metjar-mette Portage, near the source of the river Chaudière.

From this point the line coincides with the line claimed by the United States until the northwesternmost head of the Connecticut River is reached. Great Britain claimed one of several small streams to be the northwesternmost tributary of the Connecticut River, and the United States another.

The King of the Netherlands was selected in 1829 by the two Governments as the arbiter, and each laid before him, in conformity with the provisions of the convention, all the evidence intended to be brought in support of its claim, and two separate statements of the respective cases. These four statements, which embrace the arguments at large of each party, respectively, have been printed, but not published (1840).

The award of the King of the Netherlands, made in 1831, was as follows, viz :

We are of the opinion that it will be suitable (*il conviendra*) to adopt as the boundary of the two states a line drawn due north from the source of the river St. Croix to the point where it intersects the middle of the thalweg of the river St. John; thence the middle of the thalweg of that river, ascending it to the point where the thalweg of the river Saint Francis, ascending it to the source of its southwest-river St. Francis empties itself into the river St. John; thence the middle of

ernmost branch, which source we indicate on the Map A by the letter X, authenticated by the signature of our minister of foreign affairs; thence in a line drawn due west to the point where it unites with the line claimed by the United States of America and delineated on the Map A; thence said line to the point at which, according to said map, it coincides with that claimed by Great Britain, and thence the line traced on the map by the two powers to the northwesternmost source of Connecticut River.

We are of the opinion that the stream situated farthest to the northwest, among these which fall into the northernmost of the three lakes, the last of which bears the name of Connecticut Lake, must be considered as the northwesternmost head of Connecticut River.

We are of the opinion that it will be suitable (*il conviendra*) to proceed to fresh operations to measure the observed latitude in order to mark out the boundary from river Connecticut along the parallel of the forty-fifth degree of north latitude to the river Saint Lawrence, named in the treaties Iroquois or Cataraquy, in such a manner, however, that, in all cases, at the place called Rouse's Point the territory of the United States of America shall extend to the fort erected at that place, and shall include said fort and its kilometrical radius (*rayon kilometrique*).

However disposed the Government of the United States might have been to acquiesce in the decision of the arbiter, it had not the power to change the boundaries of a State without the consent of the State. Against that alteration the State of Maine entered a solemn protest by the resolutions of 19th January, 1832. And the Senate of the United States did accordingly refuse to give its assent to the award.

The arbitration of the King of the Netherlands having failed, fruitless negotiations ensued for a period of eleven years. Unsuccessful attempts were made to conclude an agreement preparatory to another arbitration. The subject became a matter of great irritation, collisions occurred in the contested territory, and for a time it seemed certain that the controversy would result in war between the two powers. In 1842, however, Great Britain gave unequivocal proof of her desire for the preservation of peace, and an amicable arrangement of the matter at issue, by the special mission of Lord Ashburton to the United States. The subject of this mission was the settlement, not only of the northeastern boundary, but the northern boundary west of the Rocky Mountains. Regarding this object of his mission, Lord Ashburton's instructions gave as the ultimatum of the English Government the boundary as above sketched (p. 14), and, naturally, his mission had no result, as far as this portion of the boundary was concerned.

An agreement was reached, however, in regard to the northeastern boundary, which, the consent of the State of Maine having been obtained, was embodied in the treaty concluded August 9, 1842.

The following is the text of the portion of this treaty relating to the boundary :

ARTICLE I. It is hereby agreed and declared that the line of boundary shall be as follows: Beginning at the monument at the source of the river St. Croix, as desig-

nated and agreed to by the commissioners under the fifth article of the treaty of 1794, between the Governments of the United States and Great Britain; thence north, following the exploring line run and marked by the surveyors of the two Governments in the years 1817 and 1818, under the fifth article of the treaty of Ghent, to its intersection with the river St. John, and to the middle of the channel thereof; thence up the middle of the main channel of the said river St. John, to the mouth of the river Saint Francis; thence up the middle of the channel of the said river St. Francis, and of the lakes through which it flows, to the outlet of the Lake Pohenagmook; thence southwesterly, in a straight line, to a point on the northwest branch of the river St. John, which point shall be ten miles distant from the main branch of the St. John, in a straight line, and in the nearest direction, but if the said point shall be found to be less than seven miles from the nearest point of the summit or crest of the highlands that divide those rivers which empty themselves into the river St. Lawrence from those which fall into the river St. John, there the said point shall be made to recede down the said northwest branch of the river St. John, to a point seven miles in a straight line from the said summit or crest; thence in a straight line, in a course about south, eight degrees west, to the point where the parallel of latitude $46^{\circ} 25'$ north intersects the southwest branch of the St. John's; thence southerly, by the said branch, to the source thereof in the highlands at the Metjarmette portage; thence down along the said highlands which divide the waters which empty themselves into the river Saint Lawrence from those which fall into the Atlantic Ocean, to the head of Hall's stream; thence down the middle of said stream till the line thus run intersects the old line of boundary surveyed and marked by Valentine and Collins, previously to the year 1774, as the 45th degree of north latitude, and which has been known and understood to be the line of actual division between the States of New York and Vermont on one side, and the British province of Canada on the other; and from said point of intersection, west, along the said dividing line, as heretofore known and understood, to the Iroquois or St. Lawrence River.

ARTICLE II. It is moreover agreed that, from the place where the joint commissioners terminated their labors under the sixth article of the treaty of Ghent, to-wit, at a point in the Neebish channel, near Muddy Lake, the line shall run into and along the ship channel, between St. Joseph and Saint Tammany islands, to the division of the channel at or near the head of St. Joseph's Island; thence turning eastwardly and northwardly around the lower end of St. George's or Sugar Island, and following the middle of the channel which divides St. George's from St. Joseph's Island; thence up the east Neebish channel, nearest to St. George's Island, through the middle of Lake George; thence west of Jonas' Island, into St. Mary's River, to a point in the middle of that river, about one mile above St. George's or Sugar Island, so as to appropriate and assign the said island to the United States; thence, adopting the line traced on the maps by the commissioners, through the river St. Mary and Lake Superior, to a point north of Ile Royale, in said lake, one hundred yards to the north and east of Ile Chapeau, which last mentioned island lies near the northeastern point of Ile Royale, where the line marked by the commissioners terminates; and from the last-mentioned point, southwesterly, through the middle of the sound between Ile Royale and the northwestern mainland, to the mouth of Pigeon River, and up the said river, to and through the north and south Fowl Lakes, to the lakes of the height of land between Lake Superior and the Lake of the Woods; thence along the water communication to Lake Salsaginaga, and through that lake; thence to and through Cypress Lake, Lac du Bois Blanc, Lac la Croix, Little Vermillion Lake, and Lake Namecan, and through the several smaller lakes, straits, or streams, connecting the lakes here mentioned, to that point in Lac la Pluie, or Rainy Lake, at the Chaudière Falls, from which the commissioners traced the line to the most northwestern point of the Lake of the Woods; thence, along the said line, to the said most northwestern point, being in latitude $49^{\circ} 23' 55''$ north, and in longitude $95^{\circ} 14' 35''$ west from the observatory at Greenwich; thence, according to existing treaties, due south to its in-

tersection with the forty-ninth parallel of north latitude, and along that parallel to the Rocky Mountains. It being understood that all the water communications and all the usual portages along the line from Lake Superior to the Lake of the Woods, and also Grand Portage, from the shore of Lake Superior to the Pigeon River, as now actually used, shall be free and open to the use of the citizens and subjects of both countries.

ARTICLE VII. It is further agreed that the channels in the river St. Lawrence, on both sides of the Long Sault islands, and of Barnhart Island; the channels in the river Detroit, on both sides of the island Bois Blanc, and between that island and both the American and Canadian shores, and all the several channels and passages between the various islands lying near the junction of the river St. Clair with the lake of that name, shall be equally free and open to the ships, vessels, and boats of both parties.

Between 1843 and 1846 there was considerable negotiation regarding the boundary west of the Rocky Mountains, resulting finally in the Webster-Ashburton treaty, which defined the boundary as far west as the straits of Juan de Fuca. The following is that portion of the treaty which defines the boundary.

TREATY WITH GREAT BRITAIN, 1846.

ARTICLE I. From the point on the forty-ninth parallel of north latitude, where the boundary laid down in existing treaties and conventions between the United States and Great Britain terminates, the line of boundary between the territories of the United States and those of Her Britannic Majesty shall be continued westward along the said forty-ninth parallel of north latitude to the middle of the channel which separates the continent from Vancouver's Island, and thence southerly through the middle of the said channel, and of Fuca's Straits to the Pacific Ocean: *Provided, however,* That the navigation of the whole of the said channel and straits south of the forty-ninth parallel of north latitude remain free and open to both parties.

ARTICLE II. From the point at which the forty-ninth parallel of north latitude shall be found to intersect the great northern branch of the Columbia River, the navigation of the said branch shall be free and open to the Hudson's Bay Company, and to all British subjects trading with the same, to the point where the said branch meets the main stream of the Columbia, and thence down the said main stream to the ocean, with free access into and through the said river or rivers, it being understood that all the usual portages along the line thus described shall, in like manner, be free and open. In navigating the said river, or rivers, British subjects, with their goods and produce, shall be treated on the same footing as citizens of the United States; it being, however, always understood that nothing in this article shall be construed as preventing, or intending to prevent, the Government of the United States from making any regulations respecting the navigation of the said river or rivers not inconsistent with the present treaty.

The above treaty extended the line westward from the Rocky Mountains to the Pacific along the forty-ninth parallel of latitude. This settled the northern boundary with the exception of the islands and passages in the straits of Georgia and of Juan de Fuca, the English claiming that the boundary should properly run through the Rosario strait, the most eastern passage, while the United States claimed that it should naturally follow the Canal de Haro.

This matter was finally settled by a reference to the Emperor of Germany as an arbitrator, who decided it in favor of the United States on

the 21st of October, 1872, thus finally disposing of our boundary with Great Britain.

ADDITIONS TO THE TERRITORY OF THE UNITED STATES.

THE LOUISIANA PURCHASE.

The region subsequently known as the territory of Louisiana was originally claimed by France, by virtue of discovery and occupation.

In 1712 France made a grant to Antoine de Crozat, of the exclusive right to the trade of this region. As this grant makes the first, and indeed the only statement of the limits of this vast region, as they were understood by France, a portion of it is here introduced.

We have by these presents signed with our hand, authorized, and do authorize the said Sieur Crozat to carry on exclusively the trade in all the territories by us possessed, and bounded by New Mexico and by those of the English in Carolina, all the establishments, ports, harbors, rivers, and especially the port and harbor of Dauphin Island, formerly called Massacre Island, the river St. Louis, formerly called the Mississippi, from the seashore to the Illinois, together with the river St. Philip, formerly called the Missouri River, and the St. Jerome, formerly called the Wabash (the Ohio), with all the countries, territories, lakes in the land, and the rivers emptying directly or indirectly into that part of the river St. Louis. All the said territories, countries, rivers, streams, and islands, we will to be and remain comprised under the name of the Government of Louisiana, which shall be dependent on the general Government of New France, and remain subordinate to it, and we will, moreover, that all the territories which we possess on this side of the Illinois, be united, as far as need be, to the general Government of New France, and form a part thereof; reserving to ourselves, nevertheless, to increase, if we judge proper, the extent of the government of the said country of Louisiana.

From this it appears that Louisiana was regarded by France as comprising the drainage basin of the Mississippi as far-north as the mouth of the Illinois, with those of all its branches which enter it below this point, including the Missouri, but excluding that portion in the southwest claimed by Spain. It is moreover certain that the area now comprised in Washington, Oregon, and Idaho was not included.

Crozat surrendered this grant in 1717.

On November 3, 1762, France ceded this region to Spain, defining it only as the province of Louisiana. A few months later, on February 10, 1763, by the treaty of peace between Great Britain, France, and Spain, the western boundary of the former's possessions in the New World, was placed in the center of the Mississippi River, thus reducing the area of Louisiana by the portion east of the Mississippi River.

By the treaty of San Ildefonso, October 1, 1800, Spain transferred back to France the balance of the province of Louisiana.

Immediately after this transfer became known, which was on November 30, 1803, measures were set on foot by President Jefferson for

securing in some way free access to the sea by way of the Mississippi River. Circumstances favored this negotiation. Bonaparte was at that time in almost daily expectation of a declaration of war by Great Britain, in which case the first act of the latter would be to seize the mouth of the Mississippi, and with it the province of Louisiana. Under these circumstances Bonaparte offered to sell the province to the United States, and the offer was promptly accepted. The consideration was 60,000,000 francs and the assumption by the United States of the "French spoliation claims," which were estimated to amount to \$3,750,000.

The treaty of cession, which bears date April 30, 1803, describes the territory only as being the same as ceded by Spain to France by the treaty of San Ildefonso.

From this it appears that the territory sold to the United States comprised that part of the drainage basin of the Mississippi which lies west of the course of the river, with the exception of such parts as were then held by Spain. The want of precise definition of limits in the treaty was not objected to by the American commissioners, as they probably foresaw that this very indefiniteness might prove of service to the United States in future negotiations with other powers. In fact, the claim of the United States to the area now comprised in Oregon, Washington, and Idaho in the negotiations with Great Britain regarding the northwestern boundary, was ostensibly based, not only upon prior occupation and upon purchase from Spain, but also upon the alleged fact that this area formed part of the Louisiana purchase. That this claim was baseless is shown not only by what has been already detailed regarding the limits of the purchase, but also by the direct testimony of the French plenipotentiary, M. Barbé Marbois. Some twenty years after the purchase he published a work upon Louisiana, in which he detailed at some length the negotiations which preceded the purchase, and, referring to this question said: "The shores of the western ocean were certainly not comprised in the cession, but already the United States are established there."

There is also contained in this work a map of the country between the Mississippi and the Pacific, on which the extent of Louisiana to the westward is indicated by a line drawn on the one hundred and tenth meridian, which is not far from the western limit of the drainage basin of the Mississippi in Wyoming and Montana. That part of the country now comprised in Oregon, Washington, and Idaho, which, it has been claimed, formed part of the purchase, bears the following legend: "Territories and countries occupied by the United States, following the treaty of cession of Louisiana."

From this it appears that the limits of the Louisiana purchase can no longer be a matter of discussion; but although the United States certainly did not purchase Oregon, as a part of Louisiana, it is no less

certain that that great area west of the Rocky Mountains fell into their hands as a direct consequence of such purchase.

FLORIDA.

The second addition to the territory of the United States consisted of the Floridas, purchased from Spain on February 22, 1819. From the date of the Louisiana purchase in 1803, the territory bounded by the Mississippi River on the west, the Perdido on the east, the parallel of 31° on the north, and the Gulf on the south had been in dispute between the two countries. During this time it had been practically in the possession of the United States. This purchase settled these conflicting claims.

The following is the clause in the treaty with Spain ceding the Floridas which defines the cession:

ART. 2. His Catholic Majesty cedes to the United States, in full property and sovereignty, all the territories which belong to him, situated to the eastward of the Mississippi, known by the name of East and West Florida, the adjacent islands dependent upon said province, etc.

A further article in this treaty defines the boundary between the United States and the Spanish Possessions in the southwest, as follows:

The boundary line between the two countries, west of the Mississippi, shall begin on the Gulph of Mexico, at the mouth of the river Sabine, in the sea, continuing north, along the western bank of that river, to the thirty-second degree of latitude; thence by a line due north to the degree of latitude where it strikes the Rio Roxo of Natchitoches, or Red River; then following the course of the Rio Roxo to the degree of longitude 100 west from London, or about 23° west of Washington; then crossing the said Rio Roxo and running thence, by a line due north, to the River Arkansas; thence, following the course of the southern bank of the Arkansas, to its source in latitude 42 north; and thence by that parallel of latitude to the South Sea, the whole being as laid down in Melish's map of the United States, published at Philadelphia, improved to the 1st of January, 1818. But if the source of the Arkansas River shall be found to fall north or south of latitude 42, then the line shall run from the said source due south or north, as the case may be, till it meets the said parallel of latitude 42, and thence along the said parallel to the South Sea, all the islands in the Sabine and the said Red and Arkansas Rivers, throughout the course thus described, to belong to the United States; but the use of the waters, and the navigation of the Sabine to the sea, and of the said rivers Roxo and Arkansas throughout the extent of the said boundary on their respective banks shall be common to the respective inhabitants of both nations.

TEXAS.

The next acquisition of territory was that of the Republic of Texas, which was admitted as a State on December 29, 1845. The area which Texas brought into the Union was limited as follows:

All the land lying east of the Rio Grande and embraced within the limits of the Rio Grande on the west and south and the boundary between the United States and Spain under the Florida treaty of 1819, on the east, viz, the Sabine River, thence north to the Red River, thence up the Red River to the one hundredth meridian west of Greenwich, thence due north to the Arkansas River, thence up the Arkansas River to its source and down the Rio Grande.

THE FIRST MEXICAN CESSION.

In 1848 a further addition was made to our territory by the treaty of Guadalupe-Hidalgo. This added to the country the area of California, Nevada, Utah, and parts of Colorado, Arizona, and New Mexico, while the Gadsden purchase, which was effected in 1853, added the remainder of Arizona and another part of New Mexico.

The treaty of Guadalupe-Hidalgo was concluded February 2, 1848, and proclaimed July 4, 1848. The clauses in it defining our acquisition of territory are as follows:

ARTICLE V. The boundary line between the two republics shall commence in the Gulf of Mexico, three leagues from land, opposite the mouth of the Rio Grande, otherwise called the Rio Bravo del Norte, or opposite the mouth of its deepest branch, if it should have more than one branch emptying into the sea; from thence up the middle of that river, following the deepest channel where it has more than one, to the point where it strikes the southern boundary of New Mexico; thence westwardly along the whole southern boundary of New Mexico (which runs north of the town called Paso) to its western termination; thence northward along the western line of New Mexico until it intersects the first branch of the river Gila (or if it should not intersect any branch of that river, then to the point on the said line nearest to such branch, and thence in a direct line to the same); thence down the middle of the said branch and of the said river until it empties into the Rio Colorado; thence across the Rio Colorado, following the division line between Upper and Lower California, to the Pacific Ocean.

The southern and western limits of New Mexico, mentioned in this article, are those laid down in the map entitled, "Map of the United Mexican States as organized and defined by various acts of the Congress of said Republic, and constructed according to the best authorities. Revised edition. Published at New York, in 1847, by J. Disturnell;" of which map a copy is added to this treaty, bearing the signatures and seals of the undersigned plenipotentiaries. And, in order to preclude all difficulty in tracing upon the ground the limit separating Upper from Lower California, it is agreed that the said limit shall consist of a straight line drawn from the middle of the Rio Gila, where it unites with the Colorado, to a point on the coast of the Pacific Ocean, distant one marine league due south of the southernmost point of the port of San Diego, according to the plan of said port made in the year 1782, by Don Juan Pantoja, second sailing-master of the Spanish fleet, and published at Madrid in the year 1802, in the atlas to the voyage of the schooners Sutil and Mexicana; of which plan a copy is hereunto added, signed and sealed by the respective plenipotentiaries.

GADSDEN PURCHASE.

Subsequently, on December 30, 1853, a second purchase was made of Mexico, consisting of the strip of land lying south of the Gila River, in New Mexico and Arizona. The boundaries as established by this, known as the Gadsden purchase, were as follows:

ARTICLE I. The Mexican Republic agrees to designate the following as her true limits with the United States for the future: Retaining the same dividing line between the two Californias as already defined and established, according to the fifth article of the treaty of Guadalupe-Hidalgo, the limits between the two republics shall be as follows: Beginning in the Gulf of Mexico, three leagues from land, opposite the mouth of the Rio Grande, as provided in the fifth article of the treaty of Guadalupe-Hidalgo; thence, as defined in the said article, up the middle of that river to the point where the parallel of 31° 47' north latitude crosses the same; thence due west one

hundred miles; thence south to the parallel of $31^{\circ} 20'$ north latitude; thence along the said parallel of $31^{\circ} 20'$ to the one hundred and eleventh meridian of longitude west of Greenwich; thence in a straight line to a point on the Colorado River twenty English miles below the junction of the Gila and Colorado Rivers; thence up the middle of the said river Colorado until it intersects the present line between the United States and Mexico.

ALASKA.

There remains but one acquisition of territory to the United States from foreign powers, viz, that of Alaska, purchased from Russia. The treaty of purchase was signed on March 30, 1867, and proclaimed June 20, 1867. The boundaries of the territory are described in the accompanying quotation from the treaty:

Commencing from the southernmost point of the island called Prince of Wales Island, which point lies in the parallel of $54^{\circ} 40'$ north latitude, and between the one hundred and thirty-first and one hundred and thirty-third degree of west longitude (meridian of Greenwich), the said line shall ascend to the north along the channel called Portland Channel as far as the point of the continent where it strikes the fifty-sixth degree of north latitude; from this last-mentioned point, the line of demarkation shall follow the summit of the mountains situated parallel to the coast, as far as the point of intersection of the one hundred and forty-first degree of west longitude (of the same meridian); and, finally, from the said point of intersection, the said meridian line of the one hundred and forty-first degree in its prolongation as far as the Frozen Ocean.

IV. With reference to the line of demarkation laid down in the preceding article, it is understood—

1st. That the island called Prince of Wales Island shall belong wholly to Russia, (now, by this cession, to the United States).

2d. That whenever the summit of the mountains which extend in a direction parallel to the coast from the fifty-sixth degree of north latitude to the point of intersection of the one hundred and forty-first degree of west longitude shall prove to be at the distance of more than ten marine leagues from the ocean, the limit between the British possessions and the line of coast which is to belong to Russia, as above mentioned (that is to say, the limit to the possessions ceded by this convention), shall be formed by a line parallel to the winding of the coast, and which shall never exceed the distance of ten marine leagues therefrom.

The western limit within which the territories and dominion conveyed are contained passes through a point in Behring's Straits on the parallel of $66^{\circ} 30'$ north latitude, at its intersection by the meridian which passes midway between the islands of Krusenstern or Iglook, and the island of Ratmanoff, or Noonerbock, and proceeds due north without limitation into the same Frozen Ocean.

The same western limit, beginning at the same initial point, proceeds thence in a course nearly southwest through Behring's Straits and Behring's Sea, so as to pass midway between the northwest point of the island of Saint Lawrence and the southeast point of Cape Choukoteki to the meridian of one hundred and seventy-two west longitude, thence from the intersection of that meridian in a southwesterly direction, so as to pass midway between the island of Attore and the Copper Island of the Kommanderski couplet or group, in the North Pacific Ocean, to the meridian of one hundred and ninety-three degrees west longitude, so as to include in the territory conveyed the whole of the Aleutian Islands west of that meridian.

The consideration paid for the Territory of Alaska was \$7,200,000, in gold.

CHAPTER II.

THE PUBLIC DOMAIN AND AN OUTLINE OF THE HISTORY OF CHANGES MADE THEREIN.

CESSIONS BY THE STATES.

At the time the Constitution was adopted by the original thirteen States, many of them possessed unoccupied territory, in some cases entirely detached and lying west of the Appalachian Mountains. Thus, Georgia included the territory from its present eastern limits westward to the Mississippi River. North Carolina possessed a narrow strip extending from latitude 35° to $36^{\circ} 30'$, approximately, and running westward to the Mississippi, including besides its own present area that of the present state of Tennessee. In like manner, Virginia possessed what is now Kentucky, while a number of States, as Pennsylvania, New York, Massachusetts, and Connecticut, laid claim to areas in what was afterward known as the Territory Northwest of the River Ohio, a region which is now comprised mainly in the States of Ohio, Indiana, Illinois, Michigan, and Wisconsin. These claims were to a greater or less extent conflicting. In some cases several States claimed authority over the same area, while the boundary lines were in most cases very ill-defined.

The ownership of these western lands by individual States was opposed by those States which did not share in their possession, mainly on the ground that the resources of the General Government, to which all contributed, should not be taxed for the protection and development of this region, while its advantages would inure to the benefit of but a favored few. On this ground several of the States refused to ratify the Constitution until this matter had been settled by the cession of these tracts to the General Government.

Moved by these arguments, as well as by the consideration of the conflicting character of the claims, which must inevitably lead to trouble among the States, Congress passed, on October 30, 1779, the following act:

Whereas the appropriation of the vacant lands by the several States during the present war will, in the opinion of Congress, be attended with great mischiefs: Therefore,

Resolved, That it be earnestly recommended to the State of Virginia to reconsider their late act of assembly for opening their land office; and that it be recommended to the said State, and all other States similarly circumstanced, to forbear settling or issuing warrants for unappropriated lands, or granting the same during the continuance of the present war.

This resolution was transmitted to the different States. The first to respond to it by the transfer of her territory to the General Government was New York, whose example was followed by the other States.

These cessions were made on the dates given below :

New York, March 1, 1781.

Virginia, March 1, 1784.

Massachusetts, April 19, 1785

Connecticut, September 13, 1786.

The Connecticut act of cession reserved an area in the northeastern part of Ohio, known as the Western Reserve. On May 30, 1800, Connecticut gave to the United States jurisdiction over this area, but without giving up its property rights in it.

South Carolina, August 9, 1787.

North Carolina, February 25, 1790.

Georgia, April 24, 1802.

The following paragraph from the deed of cession by New York defines the limits of its cession to the General Government :

Now, therefore, know ye, that we, the said James Duane, William Floyd, and Alexander M'Dougall, by virtue of the power and authority, and in the execution of the trust reposed in us, as aforesaid, have judged it expedient to limit and restrict, and we do, by these presents, for and in behalf of the said State of New York, limit and restrict the boundaries of the said State in the western parts thereof, with respect to the jurisdiction, as well as the right or pre-emption of soil, by the lines and in the form following, that is to say : a line from the northeast corner of the State of Pennsylvania, along the north bounds thereof to its northwest corner, continued due west until it shall be intersected by a meridian line to be drawn from the forty-fifth degree of north latitude, through the most westerly bent or inclination of Lake Ontario; thence by the said meridian line to the forty-fifth degree of north latitude; and thence by the said forty-fifth degree of north latitude; but if, on experiment, the above-described meridian line shall not comprehend twenty miles due west from the most westerly bent or inclination of the river or strait of Niagara, then we do, by these presents, in the name of the people, and for and on behalf of the State of New York, and by virtue of the authority aforesaid, limit and restrict the boundaries of the said State in the western parts thereof, with respect to jurisdiction, as well as the right of pre-emption of soil, by the lines and in the manner following, that is to say : a line from the northeast corner of the State of Pennsylvania, along the north bounds thereof, to its northwest corner, continued due west until it shall be intersected by a meridian line, to be drawn from the forty-fifth degree of north latitude, through a point twenty miles due west from the most westerly bent or inclination of the river or strait Niagara; thence by the said meridian line to the forty-fifth degree of north latitude, and thence by the said forty-fifth degree of north latitude.

The deed of cession by Virginia gives no limits, further than to specify that the lands transferred include only those lying northwest of the river Ohio.

The following paragraph from the deed of cession by Massachusetts gives the limits of the area ceded :

• • • We do by these presents assign, transfer, quitclaim, cede, and convey to the United States of America, for their benefit, Massachusetts inclusive, all right, title, and estate of and in, as well the soil as the jurisdiction, which the said Com-

monwealth hath to the territory or tract of country within the limits of Massachusetts charter situate and lying west of the following line, that is to say, a meridian line to be drawn from the forty-fifth degree of north latitude through the westerly bent or inclination of Lake Ontario, thence by the said meridian line to the most southerly side line of the territory contained in the Massachusetts charter; but if on experiment the above-described meridian line shall not comprehend twenty miles due west from the most westerly bent or inclination of the river or strait of Niagara, then we do by these presents, by virtue of the power and authority aforesaid, in the name and on behalf of the said Commonwealth of Massachusetts, transfer, quitclaim, cede, and convey to the United States of America, for their benefit, Massachusetts inclusive, all right, title, and estate of and in as well the soil as the jurisdiction, which the said Commonwealth hath to the territory or tract of country within the limits of the Massachusetts charter, situate and lying west of the following line, that is to say, a meridian line to be drawn from the forty-fifth degree of north latitude through a point twenty miles due west from the most westerly bent or inclination of the river or strait of Niagara; thence by the said meridian line to the most southerly side line of the territory contained in the Massachusetts charter aforesaid.

The following clause from the act of the legislature of Connecticut, authorizing the cession, defines its limits:

Be it enacted * * * That the delegates of this State, or any two of them, who shall be attending the Congress of the United States, be, and they are hereby, directed, authorized, and fully empowered, in the name and behalf of this State, to make, execute, and deliver, under their hands and seals, an ample deed of release and cession of all the right, title, interest, jurisdiction, and claim of the State of Connecticut to certain western lands, beginning at the completion of the forty-first degree of north latitude, one hundred and twenty miles west of the western boundary line of the Commonwealth of Pennsylvania, as now claimed by said Commonwealth, and from thence by a line drawn north, parallel to and one hundred and twenty miles west of the said west line of Pennsylvania, and to continue north until it comes to forty-two degrees and two minutes north latitude. Whereby all the right, title, interest, jurisdiction, and claim of the State of Connecticut to the lands lying west of said line to be drawn as aforementioned, one hundred and twenty miles west of the western boundary line of the Commonwealth of Pennsylvania, as now claimed by said Commonwealth, shall be included, released, and ceded to the United States in Congress assembled, for the common use and benefit of the said States, Connecticut inclusive.

The cession of South Carolina was described as follows:

* * * All the territory or tract of country included within the river Mississippi and a line beginning at that part of the said river which is intersected by the southern boundary line of the State of North Carolina, and continuing along the said boundary line until it intersects the ridge or chain of mountains which divides the eastern from the western waters, then to be continued along the top of said ridge of mountains until it intersects a line to be drawn due west from the head of the southern branch of Tugaloo River to the said mountains; from thence to run a due west course to the river Mississippi.

The State of North Carolina ceded—

The lands situated within the chartered limits of the State, west of a line beginning on the extreme height of Stone Mountain, at the place where the Virginia line intersects it; running thence along the extreme height of the said mountain to the place where the Watunga River breaks through it; thence a direct course to the top of the Yellow Mountain where Bright's road crosses the same; thence along the ridge of the said mountain, between the waters of Doe River and the waters of Rock Creek, to the place where the road crosses the Iron Mountain; from thence along the extreme height of the

said mountain to where Nolechucky River runs through the same ; thence to the top of the Bald Mountain ; thence along the extreme height of the said mountain to the Painted Rock, on French Broad River ; thence along the highest ridge of the said mountain to the place where it is called the Great Iron or Smoky Mountain ; thence along the extreme height of the said mountain to the place where it is called the Unicoy or Unaka Mountain, between the Indian towns of Cowee and Old Chota ; thence along the main ridge of the said mountain to the southern boundary of this State.

It will be noted that the above description of the eastern boundary of her ceded possessions agrees in general terms with the description of the western boundary of North Carolina, as given on page 96.

The articles of cession by Georgia describe the area ceded as follows :

The lands situated within the boundaries of the United States, south of the State of Tennessee and west of a line beginning on the west bank of the Chattahoochee River, where the same crosses the boundary line between the United States and Spain ; thence running up the said river Chattahoochee and along the western bank thereof to the great bend thereof, next above the place where a certain creek or river, called Uchee (being the first considerable stream on the western side, above the Cussetas and Coweta towns), empties into the said Chattahoochee River ; thence in a direct line to Nickajack, on the Tennessee River ; thence crossing the last-mentioned river, and thence running up the said Tennessee River and along the western bank thereof to the southern boundary line of the State of Tennessee.

Of the area thus ceded to the General Government, the part lying north of the Ohio was afterwards erected into the "Territory Northwest of the River Ohio," and the balance, lying south of that river, was known as the "Territory South of the River Ohio."

THE TERRITORY NORTHWEST OF THE RIVER OHIO.

This territory was bounded on the west by the Mississippi and the international boundary, on the north by the boundary line between the United States and the British Possessions, on the east by the Pennsylvania and New York state lines, and on the south by the Ohio River. It comprised an area of, approximately, 266,000 square miles. It was made up of claims of different States as follows :

1. Virginia uncontested claims, which consisted of all the territory west of Pennsylvania and north of the Ohio to the forty-first parallel of north latitude, besides her claim, by capture, as far as the northern limits of the land under the crown which had been subject to the jurisdiction of the provinces of Quebec and to Lakes Michigan and Huron.

2. The claim of Connecticut, which extended from the forty-first parallel northward to the parallel of $42^{\circ} 2'$, and from the west line of Pennsylvania to the Mississippi River.

3. The claim of Massachusetts, which extended from the north line of the Connecticut claim above noted to $43^{\circ} 43' 12''$ north latitude, and from the eastern boundary of New York to the Mississippi.

4. The belt or zone lying north of the Massachusetts claim, extending thence to the Canada line and west to the Mississippi River, was claimed to have been obtained by the treaty of peace of Great Britain, September 3, 1783.

5. At the cession by the state of Virginia, both Massachusetts and New York claimed the Erie purchase of about 316 square miles, which was subsequently bought by Pennsylvania and added to that State.

From this territory were formed the following States: Ohio, Indiana, Illinois, Michigan, Wisconsin, that part of Minnesota east of the Mississippi River, and the northwest corner of Pennsylvania.

In 1787 a bill for its provisional division into not less than three nor more than five States was passed by Congress. In this bill the limits of the proposed States were defined, corresponding in their north and south lines to the boundaries of Ohio, Illinois, and Indiana, as at present constituted. The following gives the text of the clause defining these boundaries:

CONFEDERATE CONGRESS—AN ORDINANCE FOR THE GOVERNMENT OF THE TERRITORY OF THE UNITED STATES NORTHWEST OF THE RIVER OHIO.

ARTICLE 5. There shall be formed in the said territory not less than three nor more than five States; and the boundaries of the States, as soon as Virginia shall alter her act of cession and consent to the same, shall become fixed and established as follows, to wit: The western State, in said territory, shall be bounded by the Mississippi, the Ohio, and the Wabash River; a direct line drawn from the Wabash and Post Vincents, due north, to the territorial line between the United States and Canada; and by the said territorial line to the Lake of the Woods and Mississippi. The middle State shall be bounded by the said direct line, the Wabash from Post Vincents to the Ohio, by the Ohio, by a direct line drawn due north from the mouth of the Great Miami to the said territorial line, and by the said territorial line. The eastern State shall be bounded by the last-mentioned direct line, the Ohio, Pennsylvania, and the said territorial line: *Provided, however,* And it is further understood and declared, that the boundaries of these three States shall be subject so far to be altered, that, if Congress shall hereafter find it expedient, they shall have authority to form one or two States in that part of the said territory which lies north of an east and west line drawn through the southerly bend or extreme of Lake Michigan.

Passed July 13, 1787.

The provisions of this bill seem, however, never to have been carried out. A provisional government was instituted in 1788. By act of May 7, 1800, Congress divided this territory into two territorial governments, the divisional line being a meridian passing through the mouth of the Kentucky River and extending thence northward to the Canada border. The eastern portion became the "Territory Northwest of the River Ohio," and the western portion, Indiana Territory.

On November 29, 1802, the State of Ohio, comprising most of the former, was formed and admitted into the Union, while the remnant of it was added to Indiana Territory.

In 1805, all that portion of Indiana Territory lying north of a parallel

through the most southerly bend of Lake Michigan and east of a meridian drawn through the same point became the Territory of Michigan. The boundary between these territories was subsequently very much changed, as will appear in the sequel.

By act of February 3, 1809, Indiana Territory was again divided, and the Territory of Illinois was created from the part lying west of the Wabash River and a meridian running through the city of Vincennes, extending thence to the Canada line.

In 1816 Indiana, and in 1818 Illinois, were admitted to the Union as States, each with its boundaries as constituted at present. By the same act the Mississippi River was made the western boundary of the Territory of Michigan, thus making it include all the balance of the original North-west Territory after the formation of the three States of Ohio, Indiana, and Illinois.

The act of 1834 added to Michigan Territory the land between the Missouri and White Earth Rivers on the west and the Mississippi River on the east.

Wisconsin Territory was formed in 1836 from the portion of Michigan Territory west of the present State of Michigan. On January 26, 1837, Michigan was admitted into the Union, with its present boundaries. In 1838 all that portion of Wisconsin Territory lying west of the Mississippi River and a line drawn due north from its source to the international boundary (that is, all that part which was originally comprised in the Louisiana purchase) was made the Territory of Iowa, and in 1848 Wisconsin was admitted as a State, with its boundaries as at present constituted.

This appears to leave the area which is now the northeastern part of Minnesota, lying east of the Mississippi River and a line drawn due north from its source, without any government until the formation of Minnesota Territory, in 1849.

TERRITORY SOUTH OF THE RIVER OHIO.

The "Territory South of the River Ohio" was bounded on the north by the Ohio River, on the south by the thirty-first parallel of latitude, on the east by the States of Virginia, North Carolina, South Carolina, and Georgia, and on the west by the Mississippi River. The different cessions from the States which made up this region are as follows:

1. The region ceded by Virginia, which lay between the Ohio River on the North and, nominally, the parallel of $36^{\circ} 30'$ on the south, and between the Mississippi River and her present western boundary on the east, being the region which is now the State of Kentucky.

2. The area ceded by North Carolina, which extended from $36^{\circ} 30'$ north latitude southward to 35° , and from the western boundary line of

the present State to the Mississippi River. This is now the State of Tennessee.

3. The area ceded by South Carolina, which formed a narrow belt, 12 or 14 miles in width, lying south of the thirty-fifth parallel, and extending from her western boundary to the Mississippi River. It is doubtful whether under the terms of the original charters South Carolina possessed this strip, or whether it was not included in the possessions of Georgia.

4. The area ceded by Georgia, which comprised most of the region of the present States of Alabama and Mississippi, north of the thirty-first parallel.

Kentucky was admitted to the Union on June 1, 1792; Tennessee in 1796. In 1798 Congress organized the Territory of Mississippi, which was originally a small, rectangular area, bounded on the west by the Mississippi River, on the north by the parallel through the mouth of the Yazoo River; the boundary on the east was the river Chattahoochee, and on the south the thirty-first parallel of north latitude. This area was subsequently enlarged so as to include the whole of what is now Mississippi and Alabama, with the exception of a strip along the Gulf coast, which was at that time claimed by Spain. In 1817 the territory was divided, and the eastern portion was made into Alabama Territory. Subsequently the two Territories were admitted as States.

LOUISIANA AND THE TERRITORY ACQUIRED FROM MEXICO.

The Louisiana purchase was effected in 1803. In 1804 it was divided into two parts, that portion which now comprises the State of Louisiana, with the exception of a small piece in the southeastern part, being organized as Orleans Territory, while the balance remained as the Louisiana Territory. The State of Louisiana, comprising the Territory of Orleans, was admitted to the Union in 1812, and in the same year it was enlarged by the addition of the portion lying between the Mississippi and Pearl Rivers, in the southeastern part. In the same year the name of Louisiana Territory was changed to Missouri Territory. In 1819 Arkansas Territory, having very nearly the same limits as the present State of Arkansas, was created, and in 1836 it was admitted as a State.

In 1820 the State of Missouri was formed from another portion of Missouri Territory, and in 1836 the boundaries of this State were enlarged to their present limits. In 1834, as was stated above, that portion of this Territory lying north of the State of Missouri and east of the Missouri and White Earth Rivers was attached to the Territory of Michigan. In 1836 this portion was transferred from the Territory of Michigan to the Territory of Wisconsin. In 1838 it was transferred to

the Territory of Iowa. In 1845 the State of Iowa was created, and in 1846 its boundaries were enlarged. In 1849 the remainder of the Territory was transferred to Minnesota Territory. Minnesota was admitted as a State on May 11, 1858, with its present boundaries.

Meantime Texas had been admitted to the Union, and by the treaty of Guadalupe-Hidalgo and the Gadsden purchase, we had acquired from Mexico all the area west of the northern part of Texas and south of the forty-second parallel. Furthermore, our northern boundary had been established on the forty-ninth parallel to the Pacific Ocean.

Out of this great western region were carved the following Territories :

Oregon Territory, which was formed in 1848, and which extended from the parallel of 49° north latitude southward to latitude 42°, and from the Pacific Ocean east to the summit of the Rocky Mountains.

California, which was admitted as a State in 1849, with the same limits which it possesses at present.

Utah Territory, which was formed in 1850, and which extended from the forty-second parallel southward to the thirty-seventh, and from the California boundary line eastward to the Rocky Mountains.

New Mexico, which comprised all the country lying south of Utah to the boundary line of Texas and Mexico, and from the California boundary eastward to the boundary of Texas.

Nebraska Territory, which was formed from Missouri Territory in 1854. It comprised the country from the forty-ninth parallel down to the fortieth and from the Missouri and White Earth Rivers west to the summit of the Rocky Mountains.

Kansas Territory, formed by the same act as the last, comprised the country lying west of Missouri to the boundary of New Mexico and Utah, and from the south boundary of Nebraska to the thirty-seventh parallel.

Indian Territory then had its present limits.

Washington Territory was formed in 1853 from a part of Oregon, its southern boundary being the Columbia River and the parallel of 46° north latitude, and its east line being the summit of the Rocky Mountains.

Oregon was admitted as a State in 1857, with its boundaries as at present established. The portion cut off from Oregon Territory was placed under the territorial government of Washington Territory.

Dakota Territory was formed in 1861. As originally formed it comprised all that region between its present eastern and southern boundaries, while its western boundary was the summit of the Rocky Mountains.

The Territory of Nevada was organized from the western portion of the Territory of Utah in 1861. As originally constituted, its eastern line was the meridian of thirty-nine degrees of longitude west from Washington, and its southern boundary was the parallel of thirty-seven degrees of latitude. It was admitted as a State in 1864, its eastern

boundary being made the thirty-eighth degree of longitude (approximately the one hundred and fifteenth degree west from Greenwich), while its southern boundary remained the same. In 1866, by act of Congress, the eastern boundary was moved one degree farther to the eastward, placing it upon the thirty-seventh degree of longitude west from Washington, and the triangular portion contained between the former southern boundary, the boundary of California, the Colorado River and the meridian of thirty-seven degrees of longitude was added, thus giving the State its present area and limits.

Colorado Territory was formed in 1861, with the limits of the present State. It was admitted as a State in 1876.

The Territory of Arizona was formed from New Mexico in 1863, being that portion of New Mexico lying west of the thirty-second meridian west of Washington.

In the same year Idaho was formed from parts of Dakota and Washington Territories. As originally constituted it included all the territory lying east of the present eastern limits of Oregon and Washington Territory to the twenty-seventh degree of longitude west of Washington, the latter meridian being its eastern boundary. Its southern boundary was the northern boundary of Colorado and Utah—that is, the forty-first and forty-second parallels of latitude.

From this Territory was detached, in 1864, the Territory of Montana, with its present limits, and in 1868 the Territory of Wyoming, these several changes reducing Idaho to its present dimensions.

CHAPTER III.

THE BOUNDARY LINES OF THE STATES AND TERRITORIES.

MAINE.

The first charter having any relation to the territory comprising the present State of Maine is that granted by Henry IV of France to Pierre du Gast, Sieur de Monts, in 1603, known as the charter of Acadia, which embraced the whole of North America between the fortieth and forty-sixth degrees of north latitude. Under this, several expeditions were made, and in 1606 it was decided to make a permanent settlement at Port Royal, now Annapolis, Nova Scotia, and no further attempts were made under this charter to plant colonies within the limits of the present State of Maine. (*Vide* Charters and Constitutions, p. 771.)

By the first charter of Virginia (*vide* Virginia, p.), granted by James I, in 1606, the lands along the coast of North America between

the thirty-fourth and forty-fifth degrees of north latitude were given to two companies, to one of which, the Plymouth Company, was assigned that part of North America including the coast of New England. The first colony in Maine was planted on the peninsula of Sabine, at the mouth of the Kennebec River, now Hunnewell's Point, on August 19, 1607, O. S., by George Popham.

James I in 1620 granted a charter to the Plymouth Company, in which may be found the following, viz :

Wee, therefore * * * do grant ordain and establish that all that Circuit, Continent, Precincts and Limitts in America lying and being in Breadth from Fourty Degrees of Northerly Latitude from the Equinoctial Line, to Fourty eight Degrees of the said Northerly Latitude and in length by all the Breadth aforesaid throughout the Maine Land from Sea to Sea—with all the Seas, Rivers, Islands, Creekes, Inletts, Ports and Havens within the Degrees, Precincts and Limitts of the said Latitude and Longitude shall be the Limitts, and Bounds, and Precincts of the second collony—and to the end that the said Territories may hereafter be more particularly and certainly known and distinguished, our Will and Pleasure is, that the same shall from henceforth be nominated, termed and called by the name of New England in America.

Under this grant, given in 1621, the Earl of Stirling claimed that he was entitled to land on the coast of Maine which was afterwards granted to the Plymouth Company, and by direction of James I that company issued a patent to William Alexander, Earl of Stirling,

For a tract of the main land of New England, beginning at Saint Croix and from thence extending along the sea-coast to Pemquid and the river Kennebeck. (*Vide Charters and Constitutions*, p. 774.)

The heirs of the Earl of Stirling sold this tract to the Duke of York in 1663. (*Vide Zell's Encyclopædia*.)

In 1622 Capt. John Mason and Sir Ferdinando Gorges obtained from the council of Plymouth a grant of the lands lying between the Merrimac and Kennebec Rivers, and extending back to the river and lakes of Canada. This tract was called Laconia, and it included New Hampshire and all the western part of Maine. (*Vide Whiton's New Hampshire*.)

Mason and Gorges, in 1629, by mutual consent divided their territory into two by the river Piscataqua. That part on the east of this river was relinquished to Gorges, who called it Maine. (*Vide Whiton's New Hampshire*.)

The charter of the Plymouth Company was surrendered to the King in the year 1635. (*Vide Plymouth Colony Laws*, p. 333 *et supra*.)

King Charles I, in the year 1639, granted a charter to Sir Ferdinando Gorges, which virtually confirmed the patent given to him by the Plymouth Company in 1622.

The following extract from that charter defines the boundaries :

All that Parte Purparte and Porcion of the Mayne Lande of New England aforesaid beginning att the entrance of Piscataway Harbor and soe to passe upp the same into the River of Newichewanocke and through the same unto the furthest heade thereof and from thence Northwestwards till one hundred and twenty miles bee finished and from

Piscataway Harbor mouth aforesaid Northeastwards along the Sea Coasts to Sagadahocke and up the River thereof to Kynybequy River and through the same into the heade thereof and into the Lande Northwestwards untill one hundred and twenty myles bee ended being accompted from the mouth of Sagadahocke and from the period of one hundred and twenty myles aforesaid to crosse over Lande to the one hundred and twenty myles end formerly reckoned upp into the Lande from Piscataway Harbor through Newichewanocke River and also the Northe halfe of the Isles of Shoales together with the Isles of Capawock and Nawtican neere Cape Cod as alsoe all the Islands and Ilettes lyeinge within five leagues of the Mayne all alonge the aforesaide coasts betweene the aforesaid River of Piscataway and Sagadahocke with all the Creeks Havens and Harbors thereunto belonginge and the Revercon and Revercons Remaynder and Remaynders of all and singular the said Landes Rivers and Premises. All which said Part Purpart or Porcon of the Mayne Lande and all and every the Premises herein before named Wee Doe for us our heires and successors create and incorporate into One Province or Countie, and Wee Doe name ordeyne and appoynt that the porcon of the Mayne Lande and Premises aforesaid shall forever hereafter bee called and named The Province or Countie of Mayne.

In 1664 Charles II granted to the Duke of York, who, the year before, had purchased the territory, which had been awarded to the Earl of Stirling in the division of the country to his heirs, a portion of the present State of Maine, and also certain islands on the coast, and a large territory west of the Connecticut River. (For the boundaries *vide* New York, p. 71 *et seq.*)

In 1674 Charles II made a new grant to the Duke of York, in substantially the same terms as that of 1664, including as before a portion of Maine. (*Vide* New York, p. 72.)

In the year 1677, Ferdinando Gorges, a grandson of Sir Ferdinando Gorges sold and gave a deed of the province of Maine to John Ushur, a merchant, of Boston, for £1,250. In the same year, Ushur gave a deed of the same territory to the governor and company of Massachusetts Bay, who had received a grant from the council of Plymouth in 1628, confirmed by the King in 1629. (*Vide* C. & C., p. 774.)

In 1686 Pemaquid and its dependencies, forming Cornwall County, under the jurisdiction of New York, were annexed to the New England government by a royal order, dated September 19, 1686. (*Vide* Maine Historical Society Collection, vol. 5.)

The charter of Massachusetts Bay of 1629 having been canceled in 1684, in 1691 William and Mary granted a new one, incorporating the provinces of Maine and Acadia, or Nova Scotia, with the colonies of Massachusetts Bay and of Plymouth, into one royal province by the name of the Royal Province of Massachusetts Bay. (*Vide* Mass., p. 48.)

The right of government thus acquired over the district of Maine was exercised by Massachusetts until 1819 when measures were taken to admit Maine as an independent State.

By the treaty of Paris in 1763 the King of France relinquished all claim to that portion of North America which includes the present State of Maine.

The northern and eastern boundaries were settled by the United States and Great Britain. (See p. 9, *et seq.*)

The western boundary was for a long time a source of contention between Maine and New Hampshire.

New Hampshire having been made a province in 1679, controversies arose concerning the divisional line.

In 1731 commissioners from New Hampshire and from Massachusetts having been appointed, met, but were unable to agree. New Hampshire appealed to the King, and the King ordered that a settlement should be made by commissioners from the neighboring provinces. The board met at Hampton in 1737. The commissioners fixed on—substantially—the present boundary, wording their report as follows:

Beginning at the entrance of Piscataqua Harbor, and so to pass up the same to the River Newhichawack, and thro' the same into the furthest head thereof, and thence run north 2 degrees west till 120 miles were finished, from the mouth of Piscataqua Harbor, or until it meet with His Majesty's other Governments. (See N. H. Historical Coll., Vol. II.)

This was confirmed by the King, August 5, 1740.

In 1820 Maine was admitted, as an independent State.

Difficulties having arisen about the boundary between Maine and New Hampshire, commissioners were appointed in 1827 from each State to determine the same.

In 1829 the commissioners' report was adopted by each State, and the line then settled upon is as follows, using the language of the commissioners' report, viz:

The report of the commissioners appointed by His Majesty's order in Council of February 22nd, 1735, and confirmed by his order of the 5th of August, 1740, having established—

"That the dividing line shall pass up through the mouth of Piscataqua Harbor, and up the middle of the river of Newichwannock, part of which is now called the Salmons Falls, and through the middle of the same to the farthest head thereof, &c.," and "that the dividing line shall part the Isle of *Sholes*, and run through the middle of the harbor, between the islands to the sea on the southerly side, &c." We have not deemed it necessary to commence our survey until we arrived north, at the head of Salmon Falls River, which was determined by Bryant, at his survey in 1740, to be at the outlet of East pond, between the towns of Wakefield and Shapleigh. From that point we have surveyed and marked the line as follows, viz:

We commenced at the Bryant Rock, known as such by tradition, which is a rock in the middle of Salmon Falls River, at the outlet of East pond, about six feet in length, three feet in breadth, three feet in depth, and two feet under the surface of the water, as the dam was at the time of the survey, to wit, October 1, 1827; said stone bears south, seventy-one degrees west, three rods and eight links from a large rock on the eastern bank, marked "1827," and bears also from a rock near the mill-dam (marked "H") north, nineteen degrees and thirty minutes west, and distant twelve rods and twenty-one links. At this point the variation of the needle was ascertained to be *nine degrees west*.

From the above stone the line is north seven degrees and forty-one minutes east, one hundred and seventy-eight rods to East pond, and crossing the pond three hundred and eleven rods in width to a stone monument which we erected up on the bank, about three and an half feet high above the surface of the ground, marked N on the

west side and M on the east side, which description applies to all the stone monuments hereinafter mentioned unless they are otherwise particularly described; thence the same course, two hundred and twenty-five rods, to Fox Ridge, and to a stone monument which is placed upon the north side of the road that leads from Wakefield to Shapleigh; thence two hundred rods to Balch's pond; across the pond, one hundred and three and half rods; across a peninsula, thirty-six rods; across a cove, fifty-one rods and seventeen links; across a second peninsula, forty-eight rods; across a second cove, twenty-seven rods, ten links.

Thence three hundred and seventy rods, to the road leading from Newfield to Wakefield and a stone monument, erected on the north side of the same, near Campernell's house; thence north six degrees and ten minutes east, five hundred and ninety rods, to the line of Parsonfield, to a stone monument with additional mark "1896."

At this point the variation of the needle was found to be nine degrees fifteen minutes west. Thence same course five hundred and eleven rods, crossing the end of Province pond to a stone monument on the Parsonfield road, near the house of James Andrews, also with additional mark "1828"; thence north eight degrees and thirty-eight minutes east, two hundred and eight rods, to the old corner-stone of Effingham, about two feet above the ground, and not marked; thence north eight degrees fifty-five minutes east, two hundred and seventy-seven rods, to a large round stone about three feet diameter and two feet high, marked N and M, by the road upon Towles hill; thence north seven degrees fifty-five minutes east, six hundred and thirty-one rods to a stone monument, on the road leading from Parsonfield to Effingham. At this point the variation of the needle was found to be 9 degrees thirty minutes west. Thence north five degrees two minutes east, seven hundred thirty-four to a pine stump, upon a small island in Ossipee River at the foot of the falls; thence north ten degrees east, thirty rods, to a stone monument, on the north side of the new road from Porter to Effingham; thence the same course, five hundred fifty-eight rods, to the top of Bald Mountain; thence same course, three hundred sixteen rods, to the top of Bickford Mountain; thence same course one hundred and ninety-three rods, to a stone monument, on the north side of the road, leading from Porter to Eaton.

At this point the variation of the needle was found to be nine degrees forty-five minutes west; thence north eight degrees five minutes east, seven hundred and forty-four rods, to Cragged Mountain; thence same course, sixty-seven rods, to the corner of Eaton; thence same course, seven hundred eighty-seven and an half rods, to the corner of Conway; thence same course, six hundred ten and an half rods, to a stone monument, on the south side of the road, leading from Brownfield to Conway Center; thence north eight degrees east, eight hundred seventy-one rods, to a stone monument on the south side of the road leading from Fryeburg Village to Conway. At this point the variation of the needle was found to be ten degrees west; thence same course, four rods, to a stone monument on the north side of the same road; thence north eight degrees fifteen minutes east, one hundred two rods, to Saco River; thence same course, eighteen rods, across said river; thence same course, six hundred forty-four rods, to a stone monument on the road leading to Fryeburg Village, on the north side of the river.

This monument is marked as before described, and is about eight feet high above the ground; thence same course, one hundred forty-two rods, to Ballard's Mill Pond; thence same course, sixty-one rods, six links, across said pond; thence same course, three hundred forty-four rods, to a stone monument on the east side of Chatham road; thence same course, six hundred ninety rods, to Kimball's Pond; thence same course, one hundred sixty-six rods, across said pond; thence same course, sixty rods, to a stone monument on the meadow.¹ Thence same course, nine hundred forty rods, to the corner of Bradley and Eastman's grant; thence same course, six hundred and ninety rods, to a stone monument on the east side of the Cold River road. This stone is marked as

¹ From this point the line was resurveyed in 1858, *vide* p. 38.

before described, but is not more than two feet above the ground. Thence same course, one thousand five hundred forty rods, to the corner of Warner and Gilman's location, a pile of stones. At this point the variation of the needle was found to be ten degrees twenty-three minutes west; thence same course, four hundred and fifty rods, to top of Mount Royce; thence same course, eight hundred ninety-eight rods, to Wild River; thence same course, eight rods, across said river; thence same course, seven hundred sixty-five rods, to a stone monument on the north side of the road leading from Lancaster to Bethel; thence same course, one hundred rods, to Androscoggin River; thence same course, eighteen rods, across said river; thence north eight degrees ten minutes east, four thousand one hundred sixty-two rods, across ten streams, to Chick-walnegg River; thence same course, two thousand five hundred rods, to a stone monument on the north side of the road leading from Errol to Andover. This stone is marked "N. H." and "M.," thence same course two hundred ten rods to Cambridge River, thence same course eight rods across said river, thence same course five hundred sixty-seven rods to Umbagog Lake, thence same course thirty-four rods across a cove of the same, thence same course ten rods across a peninsula of the same, thence same course two hundred twenty-five rods across a bay of said lake, thence same course two hundred six rods across a peninsula of the same, thence same course one thousand one hundred sixty-five rods across the north bay of said lake to a cedar post marked "N." "M.," thence north eight degrees east seven hundred fourteen rods to Pond brook; thence same course two hundred twenty-five rods to a stone monument on the south side of the Margalloway River, thence same course ten rods across said river, thence same course one hundred sixty-two rods to a spruce, corner of the college grant, thence same course two hundred sixty-four rods to Margalloway River a second time. At this point the variation of the needle was found to be eleven degrees forty-five minutes west; thence same course ten rods across said river, thence same course two hundred and ninety rods to same river a third time, thence same course ten rods across said river to a monument made with three stones on the north side of said river, about two feet high and not marked, thence same course four hundred forty-four rods to corner of township number five, in second range, in Maine, thence same course one thousand eight hundred six rods to the north corner of the same township, thence same course four hundred and sixty rods to a branch of Little Diamond River, thence same course three hundred fifty rods to another branch of the same, thence same course two thousand one hundred twenty rods to a branch of the Margalloway River, thence same course three hundred thirty-two rods to another branch of the same, thence same course four hundred rods to a steep mountain called Prospect Hill, thence same course nine hundred and twenty rods to Mount Carmel, sometimes called Sunday Mountain, thence same course four hundred rods to a perpendicular precipice, thence same course five hundred and forty rods to a branch of Margalloway River, thence same course two hundred and sixty rods to a branch of the same, thence same course three hundred forty-six rods to a second steep precipice, thence same course one hundred eighty-six rods to a branch of Margalloway River, thence same course two hundred forty-two rods to another branch of same river, thence same course seventy-eight rods to a beaver pond, thence same course one hundred twenty-six rods to a yellow birch tree on the highlands which divide the waters that run south from those that run into the St. Lawrence, being the northern extremity of the line and one hundred and twelve miles two hundred and thirty-three rods from the head of Salmon Falls River.

Found said tree marked on the east side "M. E. 1789," and on the west "N. H. N. E.;" also "M. 54." To these marks we added "N. H.," "N. E.," and "M. E.," "1823," "E. H.," "A. M. M.," "1828," and stones were piled round the same and marked.

The whole course of the line from the Androscoggin River was re-marked by spotting the old marked trees and crossing the spots and marking others in the course. And the line as above survey and described we agree to be the true boundary line of

said States. And the above-described marks and monuments we establish to designate the same, and that the said line hereafter remain the boundary line between the States, unless the legislature of either State shall, at the first session after the execution of this agreement, disapprove of the same.

WILLIAM KING,
RUFUS MCINTIRE,
Commissioners of Maine.

ICHABOD BARTLETT,
JOHN W. WEEKS,

Commissioners of New Hampshire.

NOVEMBER 13, 1828.

The legislature of Maine approved of the commissioners' report February 28, 1829, and requested the governor to issue his proclamation accordingly.

The same action was taken by the legislature of New Hampshire, July 1, 1829.

(For Report of Commissioners, see Laws of Maine, 1828-'9, under head of Resolves of the Ninth Legislature of the State of Maine, pages 39-43.)

Between 1828 and 1858, considerable portions of the almost unbroken forests through which the line of 1827-'28 was marked were cleared. Extensive forest fires often swept large tracts of this territory, and, as a consequence, the marks of the 1827-'28 survey for a distance of nearly eighty miles—which by that survey was mainly fixed by blazed trees,—only *seven* stone posts having been set in this distance—were obliterated, so that there remained scarcely a vestige of the original line. The lands having become valuable, and litigation in many cases being imminent, the legislatures of the two States in 1858 provided by enactment for another survey from Fryeburg to the Canada line—which was made the same year. The line as then surveyed is as follows, viz:

Commencing at an iron post^{*} situated on the line run in accordance with the "Treaty of Washington, of August 9, 1842," as the boundary between the United States and the province of Canada, at the corners of the States of Maine and New Hampshire. On the south face of said post are the words "Albert Smith, U. S. Comsr. "; on the north face, "Lt. Col. I. B. B. Eastcourt, H. B. M. Comsr. "; on the west face, "Boundary, Aug. 9, 1842 "; on the east face, "Treaty of Washington." To the marks are added on the southern half of the west face, "H. O. Kent." A large flat stone was placed on the southern face of the monument and marked "1858—N. H., Me.," on either side of a line cut in said stone bearing the direction of the State's line, viz, south, 8 degrees west.

From this point the line is south 8 degrees west, 17 rods, 7 links to a large yellow birch stub, the northern terminus of the former survey; thence 126 rods to a beaver pond; thence 73 rods to the northwesterly branch of the Margalloway, known as Kent River; thence 242 rods to another branch of the Margalloway; thence 186 rods to a certain steep precipice perpendicular on its southern face; thence 346 rods to a branch of the Margalloway River; thence 260 rods to another branch of the same; thence 540 rods to a precipice, the southern side of Mount Abbott; thence 400 rods to the summit

^{*} The position of this post is given in Hitchcock's Geological Survey of New Hampshire, as follows, viz, latitude, 45° 18' 23".33; longitude, 71° 5' 40".5.

of Mount Carmel; thence 920 rods, and across four streams, to the summit of Prospect Hill.

On this distance we marked a yellow birch tree "H. O. Kent, September 20, 1858," and the names of the remainder of the party; thence 400 rods to another branch of the Margalloway; thence 332 rods to the Little Margalloway River; thence 2,120 rods across Boesebuck Mountain to a branch of said river. On this distance at the northwest corner of township No. 5, range 3, in Maine, we marked a white birch tree, "N. H. M.," and on its north and south sides, "IV, III." Thirty rods from the summit of Boesebuck Mountain, and on its northern slope, we erected a stone monument marked "N. M.," thence 350 rods to the Little Diamond River or Abbott Brook; thence 460 rods to the northwest corner of township No. 5, range 2, in Maine. On this distance we found an ancient yellow birch tree marked "1789-35, M." To these marks we added "1858"; thence 1,806 rods to the southwest corner of the same township. On this distance, at the northeast corner of Dartmouth College, second grant in N. H., we marked a large yellow birch tree "Me., J. M. W., 1858; N. H., H. O. K.," thence, and across an open bog, 444 rods to the north bank of the Margalloway River, to a white maple tree marked "N. H. M.," thence 10 rods across said river to a large pine tree marked "M." "N. H.," thence and across a second open bog 290 rods to the same river and to a large elm stub; thence 10 rods across said river; thence 264 rods to a spruce post marked "M." "N. H.," "W. L.," "D. C.," being the southeast corner of Dartmouth College, second grant; thence 162 rods to the Margalloway River; thence 10 rods across said river to a stone monument on its southerly side, standing about 3 feet above the ground and marked "M." "N. H.," thence to the original line tree nearest to the clearing of the home farm of Z. F. Durkee, esq. *The course of the line the entire distance from the iron post at the national boundary to this point bears south eight degrees west*; thence across said clearing, the old line marks being gone, south 11 degrees and 30 minutes west, 168 rods, to the old crossed trees in the woods south of Pond Brook; thence from Pond Brook south eight degrees west, 714 rods to the north bog of Umbagog Lake and to a cedar tree marked "M." "N." To this we added "1858."

On this distance near the corner of Errol and Wentworth's location, which is a cedar post in a pile of stones, we marked a maple tree "M. 1858," "N. H. 1858"; thence south ten degrees and thirty minutes west 1,165 rods, across the north bay of said lake to the old marked trees on the southern shore; thence south eight degrees west 206 rods across the peninsula to a cedar tree marked "M." "N. H." A large stone, also, on the lake shore was marked "M." "N. H.," thence same course 225 rods, across a bay of said lake; thence same course 10 rods, across a peninsula; thence same course 34 rods across a cove; thence same course 567 rods to Cambridge River; thence same course 8 rods, across said river to a white maple stub; thence same course 210 rods to a stone monument on the north side of the road leading from Andover, Me., to Colebrook, N. H.; thence same course to the north edge of the burnt land in Grafton and Success; thence south 11 degrees west across ten streams and the Chickwalmpy River, or Silver Stream, to the old line trees bearing the crosses, easterly of the south end of Success Pond; thence on the same course south 10 degrees west following the old mark to an ash tree bearing the original cross, standing a few rods north of the house of the late Daniel Ingalls, in Shelburne; thence south 11 degrees west to a stone monument, by the road on the north side of the Androscoggin River, and to the north bank of said river, the whole distance from the stone monument near Umbagog Lake to the north bank of the Androscoggin River, being 6,662 rods; thence south 11 degrees west 18 rods across said river; thence same course 100 rods, crossing the track of the Grand Trunk Railway to a stone monument on the north side of the road leading from Lancaster, N. H., to Bethel, Me.; thence same course, 765 rods to a hemlock tree on the south bank of Wild River; thence south 66 degrees 30 minutes west 34 rods on an offset of the old survey along said south bank to the old line trees; thence following the old line trees

south 11 degrees west, passing the southeast corner of Shelburne, 898 rods to the top of Mount Royce, the whole distance being 1,881 rods. One mile north of the summit of Mount Royce we marked a beech tree "N. H." "M.," 1858; thence to a large stone marked "N. H." "Me.;" thence south 10 degrees 15 minutes west to a stone monument on the east side of the Cold River road. On this distance at the foot of the first precipice on the northern face of Mount Royce a white-birch tree was marked "1858." Further on and east of a bare ledge a white-birch tree was marked "1858," and near it, on the line, a pile of stones was erected. At the first clearing, near the north end of a stone fence, a large stone was marked "M." "N. H.;" thence along a stone fence and across a road through a piece of new growth and again crossing the road; then following another stone fence on the east side of the road, passing through a field and by the end of another stone fence; then crossing a road near the west end of a bridge over Cold River; then following the valley of that stream and crossing it six times; then crossing another road, where we placed a stone monument; then through a field, striking an old stump and pile of stones, shown as the old line and passing between a house and barn, and through the western edge of a grove of trees to the stone monument near the house of Mr. Eastman, the whole distance being 1,190 rods; thence 1,630 rods to a stone monument standing in the meadow 60 rods north of the north shore of Kimball's pond, in Fryeburg.

But as the towns of Fryeburg and Stowe have erected no durable monument on the State's line at their respective corners, we deemed it advisable, under our instructions, to proceed so far south as at least to pass the said corner and to complete the work at some well-defined monument of the old survey.

This course bore from the monument to and across an open bay south 12 degrees west; thence on the old trees south 9 degrees west 100 rods; thence on the old line south 10 degrees 30 minutes west to a stone monument erected by us near the house of Jonnet Clay, in Chatham, and on the north side of the road leading from Stowe to Chatham Corners; said monument is marked "M." "N. H." 1858; thence on the old line south 11 degrees west to the road leading from North Fryeburg to Chatham, at which point we placed a stone monument; thence south 11 degrees west to the northwest corner of Fryeburg, being a stake in a pile of stones in a piece of low ground, southerly of the house of Captain Bryant, and to the old monument, 60 rods north of Kimball's pond. On the bank north of said corner, on the south side of the road, and near Captain Bryant's house, we placed a stone monument marked "M." "N. H. 1858."

The different courses laid down in the foregoing report are the bearings of the compass in 1858 when placed on the line established in 1828. (See Legislative Journal of New Hampshire, 1859, pages 764-767.)

In 1874 the line between Maine and New Hampshire was resurveyed and marked. (*Vide* Hitchcock's Geology of New Hampshire, Vol. I, p. 173.)

NEW HAMPSHIRE.

The first charter of Virginia, granted in 1606, included the territory of the present State of New Hampshire (*vide* p. 32), as did the charter of New England, granted in 1620 (*vide* p. 33), and the grant to Capt. John Mason and Sir Ferdinando Gorges of 1622 (*vide* p. 33).

The president and council of New England made a grant to Capt. John Mason in 1629 as follows, viz:

* * * * *

(496)

All that part of the main land in New England lying upon the sea coast, beginning from the middle part of Merrimack River, and from thence to proceed northwards along the sea-coast to Piscataqua River, and so forwards up within the said river and to the furthest head thereof, and from thence northwestwards until three score miles be finished from the first entrance of Piscataqua River and also from Merrimack through the said river and to the furthest head thereof, and so forward up into the lands westward until three score miles be finished, and from thence to cross overland to the three score miles, and accounted to Piscataqua River, together with all islands and islets within 5 leagues distance of the premises and abutting upon the same, or any part or parcel thereof, &c., * * * which said portions of lands * * * the said Capt. John Mason, with the consent of the president and council, intends to name *New Hampshire*. * * *

In 1635 the grant of 1629 was confirmed by a supplementary grant, of which the following is an extract, viz:

All that part of the Mayn Land of New England aforesaid, beginning from the middle part of Naumkeek River, and from thence to proceed eastwards along the Sea Coast to Cape Anne, and round about the same to Piscataway Harbour, and soe forwards up within the river Newgewanacke, and to the furthest head of the said River and from thence northwestwards till sixty miles bee finished, from the first entrance of Piscataway Harbor, and alsoe from Naumkecke through the River thereof up into the land west sixty miles, from which period to cross over land to the sixty miles end, accounted from Piscataway, through Newgewanacke River to the land northwest aforesaid; and alsoe all that the South Halfe of the Yales of Sholes, all which lands, with the Consent of the Counsell, shall from henceforth be called New-hampshyre. And alsoe ten thousand acres more of land on the southeast part of Sagadihoc at the mouth or entrance thereof—from henceforth to bee called by the name of Massonia, &c. * * *

After the death of Capt. John Mason (in December, 1635), the affairs of the colony coming into bad condition, they sought the protection of Massachusetts in 1641 and enjoyed it till 1675, when Robert Mason, a grandson of John Mason, obtained a royal decree, under which, in 1680, a colonial government was established. But no charter was given to the colony, and its government was only continued during the pleasure of the King. The following is an extract from the commission, or decree, issued by the King in 1680:

Province of New Hampshire, lying and extending from three miles northward of Merrimack River or any part thereof into ye Province of Maine.

In the year 1690 the province of New Hampshire was again taken under the jurisdiction of Massachusetts Bay, but was again separated in 1692.

[For a history of the boundary between New Hampshire and Maine, *vide* Maine, p. 35.]

The controversy already referred to arising between the provinces of New Hampshire and Massachusetts Bay not only involved the settlement of the boundary between New Hampshire and Maine, but also that between New Hampshire and Massachusetts, and, as before stated (*vide* Maine, p. 35), the commissioners appointed by the two provinces having been unable to agree, New Hampshire appealed to the King, who

ordered that the boundaries should be settled by a board of commissioners appointed from the neighboring colonies.

The board met at Hampton in 1737, and submitted a conditional decision to the King, who in 1740 declared in council as follows, viz:

That the northern boundary of the province of Massachusetts be a similar curve line pursuing the course of the Merrimac River, at three miles distance, on the north side thereof, beginning at the Atlantic Ocean and ending at a point due north of Pawtucket Falls, and a straight line drawn from thence, due west, till it meets with His Majesty's other Governments. (*Vide* Vermont State Papers, Slade, p. 9.)

New Hampshire claimed her southern boundary to be a line due west from a point on the sea three miles north of the mouth of Merrimac River. Massachusetts claimed all the territory three miles north of any part of Merrimac River. The King's decision gave to New Hampshire, a strip of territory more than fifty miles in length and of varying width, in excess of that which she claimed. This decree of the King was forwarded to Mr. Belcher, then governor of both the provinces of New Hampshire and Massachusetts Bay, with instructions to apply to the respective assemblies to unite in making the necessary provisions for running and marking the line conformable to the said decree, and if either assembly refused, the other was to proceed *ex parte*. Massachusetts Bay declined complying with this requisition. New Hampshire, therefore, proceeded alone to run and mark the line.

George Mitchel and Richard Hazen were appointed by Belcher to survey and mark the line. Pursuant to this authority, in the month of February, 1741, Mitchel ran and marked the line from the sea-coast about three miles north of the mouth of the Merrimac River to a point about three miles north of Pawtucket Falls, and Hazen, in the month of March following, ran and marked a line from the point, three miles north of Pawtucket Falls, across the Connecticut River, to the supposed boundary line of New York, on what he then supposed to be a due west course from the place of beginning. He was instructed by Governor Belcher to allow for a westerly variation of the needle of ten degrees. (*Vide* New Hampshire Journal H. R., 1826.)

The report of the surveyors has not been preserved, but the journal of Hazen has been found, and is published in the New England Historical and General Register, July, 1879.

Subsequent investigation has proved that this line was not run on a due west course, the allowance for the westerly variation of the needle being quite too large, throwing the line north of west.

This mistake seems to have been known previous to the Revolution. In 1774 calculations were made by George Sproule, founded upon actual surveys and accurate astronomical observations, from which he determined that Hazen's line was so far north of west as to lose to the State of New Hampshire quite a large tract of land. (*Vide* New Hampshire Journal H. R., 1826.)

In 1825 commissioners were appointed by the States of New Hamp-

shire and Massachusetts to ascertain, run, and mark the line between the two States, under the proceedings of which New Hampshire asserted her claim to a due west line, conformable to the decree of 1740, it being apparent by a survey made by the commissioners that the original line was north of west. This the Massachusetts commissioners refused to do, alleging that they were only empowered to ascertain and mark the original line.

On March 10, 1827, the legislature passed a resolution providing for the erection of durable monuments to preserve the boundary line between the States of Massachusetts and New Hampshire, as the same had been run and ascertained by the commissioners; and monuments were erected accordingly. (*Vide* Resolves of Massachusetts, 1827.)

In 1830-'8 a trigonometrical survey of the State of Massachusetts was made under the direction of Simeon Borden.

A table of the latitudes and longitudes of points on the north boundary of Massachusetts, taken from that survey, will be found under Massachusetts, p. 64, from which the true course of the Hazen line, as marked by the commissioners in 1827, may be readily discovered.

Under the decree of the King of 1740 the province of New Hampshire claimed jurisdiction as far west as the territory of Massachusetts and Connecticut extended, thus including the present State of Vermont. New York claimed all the country west of the Connecticut, under the charters of 1664 and 1674 to the Duke of York. A bitter controversy ensued. The following papers serve to throw some light on the matter:

Letter from the Governor of New Hampshire to the Governor of New York.

PORTSMOUTH, November 17, 1749.

" " " I think it my duty " " " to transmit to your excellency the description of New Hampshire as the King has determined it in the words of my commission.

" " " In consequence of His Majesty's determination of the boundaries between New Hampshire and Massachusetts, a surveyor and proper chainmen were appointed to run the western line from 3 miles north of Pautucket Falls, and the surveyor upon oath has declared that it strikes Hudson's River about 80 poles north of where Mohawk's River comes into Hudson's River.

B. WENTWORTH.

(See State Papers of Vermont, Slide 1, page 10.)

The following is a description of the bounds of New Hampshire given to Governor Benning Wentworth, of province of New Hampshire, by George II, July 3, 1741:

George the Second, by the Grace of God, of Great Britain, France, and Ireland King,
Defender of the Faith, &c.

To our trusty and well-beloved Benning Wentworth, Esqr., greeting :

Know you that we, reposing especial trust and confidence in the prudence, courage, and loyalty of you, the said Benning Wentworth, out of our especial grace, certain

knowledge, and meer motion, have thought fit to constitute and appoint, and by these presents do constitute and appoint you, the said Benning Wentworth, to be our governor and commander-in-chief of our province of New Hampshire, within our dominions of New England in America, bounded on the south side by a similar curve line pursuing the course of Merrimac River at three miles distance, on the north side thereof, beginning at the Atlantick Ocean and ending at a point due north of a place called Pantucket Falls, and by a straight line drawn from thence due west cross the said river 'till it meets with our other Governments. * * *

Given at Whitehall July the 3rd, in the 15th year of His Majesty's reign.

(See Documentary History of N. York, vol. 4, page 331.)

The question of the right of territory was submitted to the King, who in 1764 made the following decree:

ORDER IN COUNCIL FIXING THE BOUNDARY BETWEEN NEW YORK AND NEW HAMPSHIRE.

[L. S.]

AT THE COURT AT ST. JAMES,

The 20th day of July, 1764.

Present: The King's Most Excellent Majesty; Lord Steward, Earl of Sandwich, Earl of Halifax, Earl of Powis, Earl of Hillsborough, Mr. Vice Chamberlain Gilbert Elliot, Esqr., James Oswald, Esqr., Earl of Harcourt.

Whereas there was this day read at the Board a report made by the right honorable the lords of the committee of council for plantation affairs, dated the 17th of this instant, upon considering a representation from the lords commissioners for trade and plantations, relative to the disputes that have some years subsisted between the provinces of New Hampshire and New York, concerning the boundary line between those provinces, His Majesty, taking the same into consideration, was pleased with the advice of his Privy Council to approve of what is therein proposed, and doth accordingly hereby order and declare the western banks of the river Connecticut, from where it enters the province of the Massachusetts Bay, as far north as the forty-fifth degree of northern latitude, to be the boundary line between the said two provinces of New Hampshire and New York. Whereof the respective governors and commanders in chief of His Majesty's said provinces of New Hampshire and New York for the time being, and all others whom it may concern, are to take notice of His Majesty's pleasure hereby signified and govern themselves accordingly.

WM. BLAIR.

(*Vide* Documentary History of New York, vol. 4, p. 355.)

Notwithstanding this decree of the King, controversy, attended with violence, was kept up for many years; but the line was finally accepted and now forms the boundary line between the States of New Hampshire and Vermont.

The northern boundary of New Hampshire was settled by the United States and Great Britain. (*Vide* p. 9 *et seq.*)

It is as follows, viz:

Commencing at the "Crown Monument," so called, at the intersection of the State of New Hampshire, Maine, and the Province of Quebec, in latitude $45^{\circ} 19' 23''.33$, longitude $71^{\circ} 5' 40''.5$, thence in an irregular line to Hall's Stream, thence down the same to the northeastern corner of Vermont, in latitude $45^{\circ} 0' 17''.58$, longitude $71^{\circ} 30' 34''.5$. (*Vide* Hitch. Geology of New Hampshire.)

VERMONT.

The grants from King Henry, of France, of 1603, and King James, of England, of 1606, both included that territory which forms the present State of Vermont. It was also included in the charter of New England of 1620.

In the grants to the Duke of York, in 1664 and 1674, all the territory between the Connecticut and Delaware Rivers was included. New York, therefore, claimed jurisdiction of the territory now known as Vermont. Massachusetts, however, at an early period, having made claim to the tract west of the Connecticut River, now a portion of that State, by the interpretation of her charter, claimed the greater part of the same territory. By the terms of the charter of Massachusetts Bay, of 1629, that colony was granted all the lands—

Which lye and be within the space of Three English myles to the northward of the said River called Monomack alias Merrymack, or to the norward of any and every Parte thereof.

Under this clause Massachusetts Bay claimed that her jurisdiction extended 3 miles north of the farthest part of the Merrimac River, which would embrace a large portion of New Hampshire and Vermont. New Hampshire contested this claim, and after several years' controversy was more than sustained by a decision of the King in 1740. New Hampshire in her turn claimed the territory of Vermont, on the ground that Massachusetts and Connecticut, having been allowed to extend their boundaries to within 20 miles of the Hudson River, her western boundary should go equally as far, and contended that the King's decree of 1740 left that fairly to be inferred; also, that the old charters of 1664 and 1674 were obsolete.

By a decree of the King, however, the territory west of the Connecticut River, from the 45th parallel of north latitude to the Massachusetts line, was declared to belong to the province of New York. (*Vide* New Hampshire, p. 44.)

As most of the settlers of Vermont were from New Hampshire, this decision of the King caused great dissatisfaction, and the Revolution found Vermont the scene of conflicting claims, and the theatre of violent acts, culminating, in some instances, in actual bloodshed.

On January 15, 1777, Vermont declared herself independent and laid claim to the territory west as far as the Hudson River, and from its source north to the international boundary, including a tract along the west shore of Lake Champlain. A part of New Hampshire, also, at one time, sought a union with Vermont.

In 1781 Massachusetts assented to her independence. She adjusted her differences with New Hampshire in 1782, but eight years more passed before New York consented to her admission into the Union.

In 1791 Vermont was admitted as an independent State, but was required to restrict her boundaries to their present extent.

The act of New York, of March 6, 1790, giving her consent to the admission of Vermont, defines her boundaries. (*Vide* Slade's Vermont, p. 507.)

The northern boundary was settled by the United States and Great Britain by the treaty of Washington, in 1842. (*Vide* p. 16.)

The eastern boundary is low-water mark on the west bank of the Connecticut River. (*Vide* New Hampshire, p. 44.)

The southern boundary was settled by the decree of 1740. (*Vide* New Hampshire, p. 42.)

The line between Vermont and New York was surveyed and marked by commissioners from the two States in 1814, and is as follows, viz :

Beginning at a red or black oak tree, the northwest corner of Massachusetts, and running north $82^{\circ} 20'$ west as the magnetic needle pointed in 1814, 50 chains, to a monument erected for the southwest corner of the State of Vermont, by Smith Thompson, Simon De Witt, and George Tibbitts, commissioners on the part of New York, and Joseph Beeman, jr., Henry Olin, and Joel Pratt second, commissioners on the part of the State of Vermont, which monument stands on the brow of a high hill, descending to the west, then northerly in a straight line to a point which is distant 10 chains, on a course, south 35° degrees west, from the most westerly corner of a lot of land distinguished in the records of the town of Pownal, in the State of Vermont, as the fifth division of the right of Gamaliel Wallace, and which, in the year 1814, was owned and occupied by Abraham Vosburgh; then north 35° degrees east to said corner and along the westerly bounds of said lot, 30 chains to a place on the westerly bank of Hasick River, where a hemlock tree heretofore stood, noticed in said records as the most northerly corner of said lot; then north 1° degree and 20 minutes west, 6 chains to a monument erected by the said commissioners, standing on the westerly side of Hasick River, on the north side of the highway leading out of Hasick into Pownal, and near the northwesterly corner of the bridge crossing said river; then north 27° degrees and 20 minutes east, 30 chains, through the bed of the said river, to a large roundish rock on the northeasterly bank thereof; then north 25° degrees west, 16 chains and 70 links; then north 9° degrees west, 18 chains and 60 links, to a white-oak tree, at the southwest corner of the land occupied in 1814 by Thomas Wilsey; then north 11° degrees east, 77 chains to the north side of a highway, where it is met by a fence dividing the possession of said Thomas Wilsey, jr., and Emery Hunt; then north 46° degrees east, 6 chains; then south 66° degrees east, 26 chains and 25 links; then north 9° degrees east, 27 chains and 50 links to a blue-slate stone, anciently set up for the southwest corner of Bennington; then north 7° degrees and 30 minutes east, 46 miles 43 chains and 50 links to a bunch of hornbeam saplings on the south bank of Poultney River, the northernmost of which was marked by said last-mentioned commissioners, and from which a large butternut tree bears north 70° degrees west, 30 links, a large hard maple tree, south 2 chains and 86 links, and a white ash tree on the north side of said river, north 77° degrees east.

Which said several lines from the monument erected for the southwest corner of the State of Vermont were established by said last-mentioned commissioners, and were run by them, as the magnetic needle pointed, in the year 1814, then down the said Poultney River, through the deepest channel thereof to East Bay; then through the middle of the deepest channel of East Bay and the waters thereof to where the same communicate with Lake Champlain; then through the deepest channel of Lake Champlain to the eastward of the islands called the Four Brothers, and the westward of the islands called the Grand Isle and Long Isle, or the Two Heroes, and to the west-

ward of the Isle La Motte to the line in the 45th degree of north latitude, established by treaty for the boundary line between the United States and the British Dominions. (See Revised Statutes of New York, Banks & Brothers, sixth edition, Vol. I, pp. 122-123.)

This line was changed in 1876 by a cession of a small territory from Vermont to New York, described as follows, viz :

All that portion of the town of Fairhaven, in the county of Rutland, and State of Vermont, lying westerly from the middle of the deepest channel of Poultney River as it now runs, and between the middle of the deepest channel of said river and the west line of the State of Vermont as at present established. (Ratified by Congress April 7, 1880.)

MASSACHUSETTS.

The territory of Massachusetts was included in the first charter of Virginia, granted in 1606, (*Vide* Virginia p., 88) and in the charter of New England, granted in 1620, (*Vide* Maine p. 33.)

In 1628 the council of Plymouth made a grant to the governor and company of Massachusetts Bay in New England, which was confirmed by the King, and a charter was granted in 1629, of which the following are extracts :

* * * Nowe Knowe Yee, that Wee * * * have given and granted * * * all that Parte of Newe England in Amirica which lyes and extends betweene a great River there commonlie called Monomack River, alias Merrimack River, and a certen other River there, called Charles River, being in the Bottome of a certen Bay there, comonlie called Massachusetts alias Mattachusetts, alias Massatusetts Bay, and also all and singuler those Landes and Hereditament whatsoever, lying within the Space of Three Englishe Myles on the South Parte of the said River called Charles River, or of any or every Parte thereof. And also all and singuler the Landes and Hereditaments whatsoever, lying and being with the space of Three Englishe Myles to the southward of the southermost Parte of the said Baye, called Massachusetts, alias Mattachusetts, alias Massatusetts Bay—and also all those Lande and Hereditaments whatsoever, which lye and be within the space of Three English Myles to the Northward of the saide River, called Monomack, alias Merrymack, or to the Norward of any and every Parte thereof and all Landes and Hereditaments whatsoever, lying within the Lymitts aforesaide, North and South, in Latitude and Bredth, and in Length and Longitude, of and within all the Bredth aforesaide, throughout the Mayne Landes there from the Atlantick and Western Sea and Ocean on the East Parte, to the South Sea on the West Parte.

* * * Provided alwayes, That yf the said Landes * * * were at the tyme of the graunting of the saide former Letters patents, dated the Third Day of November, in the Eighteenth yeare of oursaid deare Fathers Raigne aforesaide, actuallie possessed or inhabited by any other Christian Prince of State, or were within the Boundes Lymitts or Territories of that Southern Colony, then before graunted by our saide late Father * * * That then this present Graunt shall not extend to any such partes or parcells thereof * * * but as to those partes or parcells * * * shal be vtterlie voyd, these presents or any Thing therein conteyned to the contrarie notwithstanding * * *

The charter of New England was surrendered to the King in 1635. (*Vide* Plymouth Colony Laws, p. 333.)

The charter of 1629 was canceled by a judgment of the high court of chancery of England, June 18, 1684. (*Vide C. & C.*, p. 942.)

In the year 1686, Pemaquid and its dependencies were annexed to the New England government. (*Vide Maine*, p. 34.)

In 1691 a new charter was granted to Massachusetts Bay, which included Plymouth Colony and the Provinces of Maine and Nova Scotia. The following are extracts from this charter:

* * * Wee * * * do will and ordeyne that the Territories and Collonyes Commonly called or Known by the names of the Collony of the Massachusetts Bay and Collony of New Plymouth the Province of Main the Territorie called Accadia or Nova Scotia and all that tract of Land lying betweene the said Territories of Nova Scotia and the said Province of Main be erected Vnited and Incorporated * * * into one reall Province by the Name of Our Province of the Massachusetts Bay in New England. * * *

All that parte of New England in America lying and extending from the greate River comonly called Monomack als Merrimack on the Northpart and from three Miles Northward of the said River to the Atlantick or Western Sea or Ocean on the South part And all the Lands and Hereditaments whatsoever lying within the limitts aforesaid and extending as farr as the Outermost Points or Promontories of Land called Cape Cod and Cape Mallabar North and South and in Latitude Breadth and in Length and Longitude of and within all the Breadth and Compass aforesaid throughout the Main Land there from the said Atlantick or Western Sea and Ocean on the East parte towards the South Sea or Westward as far as Our Collonyes of Rhode Island Connecticut and the Narragansett Countrey all alsoe all that part or porcion of Main Land beginning at the Entrance of Piscataway Harbour and soe to pass vpp the same into the River Newickewannock and through the same into the furthest head thereof and from thence Northwestward till One Hundred and Twenty miles be furnished and from Piscataway Harbour mouth aforesid North-Eastward along the Sea Coast to Sagadehock and from the Period of One Hundred and Twenty Miles aforesaid to crosse over Land to the One Hundred and Twenty Miles before reckoned up into the Land from Piscataway Harbour through Newickawannock River and alsoe the North halfe of the Isles and Shoales together with the Isles of Cap-pawock and Nantukett near Cape Cod aforesaid and alsoe [all] Lands and Hereditaments lying and being in the Countrey and Territory comonly called Accadia or Nova Scotia And all those Lands and Hereditaments lying and extending betweene the said Countrey or Territory of Nova Scotia and the said River of Sagadahock or any part thereof And all Lands Grounds Places Soiles Woods and Wood grounds Havens Ports Rivers Waters and other Hereditaments and premisses whatsoever, lying within the said bounds and limitts aforesaid and every part and parcell thereof and alsoe all Islands and Isetts lying within tenn Leagues directly opposite to the Main Land within the said bounde. * * *

(For an account of the settlement of the boundary between the District of Maine, formerly a part of Massachusetts, see *Maine*, p. 35.)

The present northern boundary of Massachusetts was settled in 1741. (For history, see *New Hampshire*, p. 43.)

The boundary line between Massachusetts and Rhode Island was for more than two hundred years a question of dispute, and was, in some respects, the most remarkable boundary case with which this country has had to do. Twice the case went to the Supreme Court of the United States, and in one of these suits Daniel Webster and Rufus Choate were employed as counsel for Massachusetts.

As early as 1642 the line between the two colonies was marked in part by Nathaniel Woodward and Solomon Saffrey, who set up on the plain of Wrentham a stake as the commencement of the line between Massachusetts Bay and Rhode Island. This stake was by them supposed to mark a point 3 miles south of the Charles River.

The report of these commissioners has not been found, but frequent reference is made to their survey in the record of the subsequent controversies and litigations.

In 1710-11 commissioners appointed from Massachusetts and Rhode Island agreed upon the north line of Rhode Island. The action of the commissioners was approved by the legislatures of both colonies.

The agreement was as follows, viz :

That the stake set up by Nathaniel Woodward and Solomon Saffrey, skillful, approved artists, in the year of our Lord 1642, and since that often renewed in the latitude of $41^{\circ} 55'$, being 3 English miles distant southward from the southernmost part of the river called Charles River, agreeable to the letters patent for the Massachusetts Province, be accounted and allowed on both sides the commencement of the line between the Massachusetts and the colony of Rhode Island, from which said stake the dividing line shall run, so as it may (at Connecticut River) be $2\frac{1}{2}$ miles to the southward of a due west line, allowing the variation of the compass to be 9° ; which said line shall forever, &c. (*Vide Howard's Reports, S. C., Vol. 4, p. 631, et seq.*)

In 1719 this line was run by commissioners appointed for the purpose. Subsequent investigation has shown that this line was run in a very irregular manner. (*Vide R. I. Acts, May, 1867, page 6, et seq.*)

The line between Massachusetts and the eastern part of Rhode Island was fixed by commissioners in 1741, from the decision of whom the colony of Rhode Island appealed to the King, who, in the year 1746, affirmed their decision by a royal decree.

The following is a record of the proceedings in council, together with the royal decree.

[Council Office. Council Register. Geo. II, No. 8, p. 204.]

AT THE COURT AT KENSINGTON
the 29th day of July 1742.

Present. The Kings Most Excellent Majesty, Archbp^d of Canturbury, Earl of Pembroke, Lord President Earl of Winchelsea, Lord Privy Seal Earl of Grantham, Duke of Bolton, Earl of Cholmondely, Duke of Rutland, Earl of Wilmington, Marq^s of Tweedale, Earl of Bath, Visco^t Lonsdale, Mr. Chancellor of the Excheq^r, Lord Delaware, Sr Charles Wager, Lord Bathurst, Sr. William Younge, Lord Monsore, Sr John Norris, Mr Speaker Thomas Winnington Esq., Mr. Vice Chamberlin, George Wade Esq.

Upon reading this day at the board the humble Petetion and appeale of the Governor and company of the English of Rhode Island and Providence Plantations in New England in America from several particular parts of the determination of the commissioners appointed by his Majesty to settle the Boundary's of the said colony Eastwards with the Province of Massachusetts Bay, and humbly praying that a day may be appointed for hearing said appeal, and that the particular parts of the said commissioners determination appealed from may be reversed, and such other deter-

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mination made instead thereof as shall be agreeable to the true construction of the Boundaries contained in the Royal Charter under which the Petitioners claim, It is ordered by his Majesty in Council that the said Petition and appeal (a copy whereof is hereunto annexed). Be and it is hereby referred to the Right Honorable the Lord of the committee of council for hearing appeals from the Plantations to hear the same, and report their opinion thereupon to his Majesty at the Board.

A true copy.

I. B. LENNARD.

Collated with the original entry in the Council Register, 18 Jan'y, 1845.

ROBT. LEMON.

[Council Office. Council Register. Geo. II, No. 8 p. 235.]

AT THE COURT OF KENSINGTON,
the 15th day of Sept. 1742.

Present, The Kings most Excellent Majesty Archbp of Canturbury, Lord Delmar Lord Chancellor, Mr Vice Chamberlin, Duke of Richmond, Mr. Chancellor of the Exchequer, Duke of Newcastle, Harry Pelham Esq. Earl of Winchelsea, Thomas Warrington Esq Earl of Wilmington George Wade Esq. Lord Cartaret.

Upon reading this day at the Board the humble Petition and appeale of His Majesty's Province of the Massachusetts Bay in New England from the determination of the commissioners appointed by His Majesty to settle the Boundary of the Colony of Rhode Island Eastwards, with the said province of Massachusetts Bay and humbly praying that a day may be appointed for hearing the said appeale and that the determination of the said commissioners may be reversed, and such other determination made instead thereof as shall be agreeable to the petitioners claim exhibited before the said commissioners—It is ordered by his Majesty in council that the said petition and appeale (a copy whereof is hereunto annexed) Be and it is hereby referred to the Right Honorable the Lords of the committee in council for hearing appeals from the Plantations to hear the same and report their opinion thereupon to His Majesty at the Board.

A true copy.

I. B. LENNARD.

Collated with the original entry in the Council Registry, 18 of Jan'y, 1845.

ROBT. LEMON.

[Ordered in Council, dated 28th May, 1746. Council office. Council Register. Geo. II, No. 10, p. 493.]

AT THE COURT OF KENSINGTON,
the 28th day of May 1746.

Present the Kings Most Excellent Majesty in Council.

Upon reading at the Board a Report from the Right Honourable the Lord of the committee of council for hearing appeals from the Plantations dated the 11th of December 1744 in the words following vizt.

Your Majesty having been pleased by Your Order in council of the 29th of July 1742 to refer unto this committee the humble petition and appeale of the Governor and company of the English Colony of Rhode Island and Providence Plantations in New England in America, from several particular parts of the determination of the commissioners appointed by your Majesty to settle the Boundaries of said colony eastwards with the Province of Massachusetts Bay and humbly praying that the particular parts of the said commissioners determination appealed from may be reversed, and such other determinations made instead thereof, as shall be agreeable to the true construction of the Boundaries continued in the Royal Charter under which the petitions claim—and your Majesty having been also pleased by another order in council of the 15th of September 1742, to refer unto this committee, the humble Petition and appeal of your Majesty's Province of the Massachusetts Bay in New England parts of

the said determination of the said commissioners, and humbly praying that the same may be reversed and set aside and that instead thereof Your Majesty will be graciously pleased to give such judgement and determinations as shall be agreeable to the petitioners claim exhibited before the said commissioners. The Lords of the committee in obedience to your Majesty's said orders of Reference, have met several times, and taken both the said Petitions of Appeal into their consideration, and having examined into the Proceedings of the said commissioners, do find that they pronounced their judgements or determination on the 30th of June 1741 in the words following:

The court took into consideration, the charters, Deeds and other Evidences, Claims Pleas and allegations produced and made by party referring to the controversy before them and after mature advisement, came to the following Resolutions: That there is not any one Evidence proving that the Water between the Main Land on the East, and Rhode Island on the West, was ever at any time called Naragansett River, that though there be evidence that the place where the Indian called King Philip lived near Bristol, was called Pawconoket, and that another place near Swansey was called Sowams or Sowamsett, yet no evidence has been produced of the extent of the Pawconoket country to Seaconk, or Pawtucket River, as it runs to the line of the late Colony of the Massachusetts Bay, for tho' there be some evidence that the Indians at enmity with King Philip, or with other Indians in enmity with him, lived on the west side of the said River, and that the Indians subject to King Philip, or in amity with him, lived on the East side of the said River there is no Evidence that all the Indians subject to, or in amity with King Philip, lived in the Pawconoket Country. That the Province not having produced the Letters Patent, constituting the council of Plymouth, nor any copy thereof, the Recital of said Letters Patent in the deed from the council of Plymouth, to Bradford and his associates, is not sufficient evidence against the Kings Charter. That the council of Plymouth being a Corporation, could not create another corporation, and that no Jurisdiction within the Kings Dominions in America can be held by Prescription or on the Foot of Prescription. That the determination of the boundaries of the colony's of Rhode Island and New Plymouth by the Kings Commissioners in the year 1664 appear to have been only a temporary order for preserving the Peace on the Borders of both Colonys without determining the Rights and Titles of either. Upon the whole nothing appears whereby the Colony of Rhode Island and Providence plantations can be barred or hindered from extending their Jurisdiction Eastward towards the Province of the Massachusetts Bay according to the true intents and meaning of their charter. But some dispute having arisen between the Partys as to the true construction and meaning thereof, the court is of opinion, That the Narragansett Bay is and extendeth itself from Point Judith in the west to Seaconet Point on the East and including the Islands therein, layeth and extendeth itself unto the mouth of the River which runnith towards the town of Providence and that as it so lies or extends, it has and may be considered as having one Eastern Side at the Eastern coast of the said Bay runs up northerly from Seconets Point,—and one other North Eastern Side from near Mount Hope to Bullocks Neck, as the said Bay runs up North Westerly towards the Town of Providence and that the land adjacent to the said North Eastern and Eastern Coasts and including within the following lines and the said Bay are within the Jurisdiction of the Colony of Rhode Island; Vizt on the North East side of the said Bay—one line running from the south west corner of Bullocks Neck, Northeast three Miles. One other line running from the Northeast extremity of the said line until it be terminated by a line three miles Northeast from the northeasternmost part of the Bay on the west side of Rumatick Neck, and one other line from the termination of the west line to the Bay, at or near Towocet Neck, running so that it touch the North East extremity of a line running three miles North East from the North East corner of Bristol Harbour, and on the Eastern side of the said Bay; One line from a certain point on the Eastern side of the said Bay opposite to the southernmost part of the Shawmuts Neck, and

four hundred and forty Rods to the Southwards of the Mouth of Fall River running East three miles; One other line running from the Easternmost extremity of the said line till it be terminated by the Easternmost end of a line three miles East from the Easternmost part of a cove in the said Bay which is to the southward of Nawquaket and one other line from the termination of the last line to the sea, running on such course, as to be three miles East from the Easternmost part of the Bay adjoining to Scitcheu-west on Rhode Island, and that the said Distances of three miles East and Northeast, are to be measured from high Water Mark, and this court doth hereby settle, adjust and determine, that the Eastern Boundary of the said Colony of Rhode Island and Providence Plantations, towards the Massachusetts Bay, is, shall be and runs from a certain Pointe (where a Meridian line passing through Pawtucket Falls, cuts the South Boundary of the Colony of Massachusetts Bay), south to Pawtucket Falls, Then southerly along the eastward side of Seaconk River, and the River which runnith towards the Town of Providence, to the Southwest corner of Bullock's Neck, then Northeast three miles; and then along the aforesaid lines running at three miles distance from the Easternmost parts of the said Bay to the said Bay, at or near Towoset Neck. Then as the said Bay runs to the southernmost point of Shawmut Neck, and then in a straight line to the aforesaid point opposite to the said Neck. Then East three miles and then along the aforesaid lines, running at three miles distance from the Easternmost parts of the said Bay, to the sea. All which lines are to be run by making the proper allowance for the variation of the Magnetic Needle from the Meridian. And for the better understanding of the description of the lines before mentioned; the Court hath caused the Boundary lines of the lands adjacent to the said most eastern and Northeastern points of the Said Bay, to be delineated on the Map or Plan of the said Bay and countries adjacent now in court, and the same are distinguished on the said Map or Plan, by A, B, C, D, E, F, G, H.

The Lord of the Committee having considered the whole matter and heard all partys concerned therein by their Council learned in the Law, Do agree humbly to report to your Majesty as their opinion, That the said Judgment or determination of the said Commissioners should be affirmed, and both the Petitions of Appeal therefrom dismissed.

His Majesty this day took the said Report into consideration and was pleased with the advice of the Privy Council to approve thereof, and to order, that the said Judgment or Determination of the said Commissioners, Be, and it is hereby Affirmed And both the said Petitions of Appeal therefrom dismissed.

Whereof the Governor or the Commander in Chief of His Majesty's Province of the Massachusetts Bay, The Governor and Company of the colony of Rhode Island and Providence Plantations for the time being, and all others whom it may concern, are to take notice and govern themselves accordingly.

A true Copy.

I B LENNARD.

Colated with the Original entry in the Council Register, 18 January, 1745.

ROBT LEMON.

Under the foregoing decree the line was run by commissioners appointed for the purpose, whose report was as follows, viz:

We, the subscribers, appointed commissioners by the general assembly of the colony aforesaid, to mark out the bounds of said colony eastward towards the province of Massachusetts Bay, agreeable to His Majesty's royal determination in council, the 28th day of May, 1746, did in pursuance thereof, on the second day of December last past, meet at Pawtucket Falls, in expectation of meeting with commissioners that might be appointed by the province of the Massachusetts Bay, for the purpose aforesaid; and after having there tarried till the afterpart of said day, and no commissioners in behalf of the said province appearing, we proceeded to run a due north line

from Pawtucket Falls to the south boundary of the aforesaid province of the Massachusetts Bay, in manner following, viz: From a certain point on the southern side of Pawtucket Falls, where we erected a monument of stones, with a stake thereon, we run a meridian line which directly passed through said falls, to a walnut tree on the northerly side of said falls; then to a pitch pine tree; then to a small white oak; then to a grey oak; then to a small bush; then to another small bush with stones about it; then to a heap of stones with a stake thereon; then to a black oak tree; then to another black oak; then to a small pitch pine; then to a black oak; then to a large white oak near the river, called Abbot's Run; then to a poplar tree; then to a heap of stones with a stake thereon; then to a large rock with stones thereon; then to a small black oak tree; then to a walnut tree; then to a black oak; then to divers other marked trees in the said course, to the extremity of said line; and when we came near the termination of the said line made a monument of stones, there being no noted south boundary of the said province near the said line, and therefore, for the discovery of the south boundary of the said province, upon the best information we could obtain, proceeded to Wrentham Plain, at or near to a place where was formerly erected a stake, called Woodward's and Saffery's stake, as one remarkable south boundary of the said province, and from thence run a west line, making an allowance of eight degrees and a half as the west variation of the magnetic needle from the true meridian, it being the course of the south line of the said province, according to their charter (as we apprehended), and then we extended the said north line from the aforesaid monument till it intersected the said west line, and upon the point of its intersection erected a monument of stones with a stake thereon, as the northeast boundary of that tract of land commonly called the Gore.

After which we proceeded to Bullock's Neck, and on the southeast corner thereof erected a red cedar post, marked with the letters J. H. C. R., with the figure of an anchor thereon, and from thence running a line northeast making the same allowance for the variation aforesaid, to a black oak tree marked with the letters G. C. C. R., then to a large white oak marked with the letters G. B. C. R., then to a white oak post, set in the ground with a heap of stones around it, marked with the letters G. W. C. R., with the figure of an anchor thereon, being three miles distant from Bullock's Neck aforesaid.

After which we proceeded to the northeasternmost part of the bay on the west side of Rumstick Neck, and from a point where a locust post was erected, run a line three miles northeast, with the same allowance for the variation and at the extremity of the said line erected a monument of stones, from which we run a line to the northeast extremity of that line drawn from the southwest corner of Bullock's Neck aforesaid, the course whereof being west thirty-eight degrees north, according to the magnetic needle, the distance of nine hundred and fifty-five rods, marking trees and making other boundaries in the course of said line. After which we proceeded to the northeast corner of Bristol Harbour, and from high-water mark, which was some rods distant northeast from the bridge leading to Swansey Ferry, we ran a line three miles northeast, still making the same allowance for the variation, and at the extremity of which line we erected a monument of stones; then we ran a line from the northeast extremity of the line drawn from Rumstick aforesaid, the course whereof being south twenty-five degrees east, till it met with the termination of the line drawn from Bristol Harbour aforesaid, the distance whereof being nine hundred and twenty-seven rods; and from thence to a straight line to the bay at Towoset Neck, making proper boundaries in the course of said line.

After which we proceeded to the eastern side of the Narragansett Bay, and on the easternmost part of a cove in the said bay, which is southward of Nanequachet, ran a line three miles east (still making the same allowance for variation), at the extremity whereof we marked a grey oak tree with the letters C. R., with the figure of an anchor thereon.

After which we proceeded to the mouth of Fall River, and from thence measured

four hundred and forty rods southerly on the shore, as the said shore extendeth itself from the mouth of said Fall River, and from the point where the said four hundred and forty rods reached, being east thirty-five degrees south of the southernmost point of Shawomet Neck, we ran a line three miles east, with the same allowance for the variation; in the course whereof we marked divers trees, and came to a large pond, on the west of which was a small oak between two large rocks, and from thence measured over the said pond to a bunch of maples, two whereof we marked with the letters I and F, standing on a place called Ralph's Neck, being the extremity of the said three miles; from thence we ran a line south twenty degrees west, two thousand one hundred and twenty-three rods (making proper boundaries in said line), till we met the termination of the three-mile line, ran from the cove southward of Nanequachet aforesaid.

After which we proceeded to a place called Church's Cove, in said bay, and ran a line three miles east, making the same allowance for the variation aforesaid, and at the extremity whereof, and near the sea, we erected a monument of stones, and from thence ran a line north two degrees and a quarter east, one thousand and nine hundred and forty-one rods, till it also met the termination of the said line, drawn from the first mentioned cove as aforesaid, making proper boundaries in the course of said line.

The foregoing is a just account of our proceedings, and report the same accordingly.

J. HONEYMAN, JR.
GEORGE WANTON.
GIDEON CORNELL.
GEORGE BROWN.

And it is voted and resolved, That the said report be, and it is hereby, accepted by this assembly.

In the year 1748 the legislature of Rhode Island appointed commissioners to continue the line to the Connecticut River, recognizing the Woodward and Saffrey stake as the place of beginning. Massachusetts failed to appoint commissioners, whereupon the Rhode Island commissioners proceeded to complete the running of the line. In their report they say—

That we not being able to find any stake or other monument which we could imagine set up by Woodward and Saffrey, but considering that the place thereof was described in the agreement mentioned in our commission, by certain invariable marks, we did proceed as followeth, namely: We found a place where Charles River formed a large current southerly, which place is known to many by the name of Pappataliah Pond, which we took to be the southernmost part of said river, from the southernmost part of which we measured three English miles south, which three English miles did terminate upon a plain in a township called Wrentham. (See Howard's Reports S. C., vol. 4, page 632).

From this point they ran the line. From this time forward repeated steps were taken by Rhode Island by resolutions, and by appointment of commissioners at different times to ascertain and run the line, in connection with commissioners from Massachusetts; commissioners from both colonies met more than once, but they failed to agree upon a boundary in place of that established under the agreements of 1711-'18. Rhode Island alleged a mistake in her commissioners, in the place of beginning (that is, on Wrentham Plain), as the ground of these efforts.

This controversy, however, embraced the entire line from the State of

Connecticut to the Atlantic Ocean. Massachusetts asserted that an encroachment had been made on her territory from Burnt Swamp Corner to the ocean by Rhode Island, who, on her part, claimed that the jurisdictional line of Massachusetts from said corner to the Connecticut line was, in its whole extent, upon the territory of Rhode Island. The legislatures of the respective States having failed, after repeated effort, to adjust the controversy, Rhode Island in 1832, by a bill in equity, brought the subject of the northern boundary, from Burnt Swamp Corner to the Connecticut line, before the Supreme Court of the United States, which in 1846 decided that the jurisdictional line claimed by Massachusetts was the legal boundary of the two States between these points.

While this suit was pending an attempt was made to settle the long controversy by an amicable adjustment of the whole line from Connecticut to the ocean. Commissioners were appointed by both States in 1844 to ascertain and mark the true boundary from Pawtucket Falls to Bullock's Neck. In 1845 the same commissioners were authorized to ascertain the line from Burnt Swamp Corner to the Atlantic Ocean.

In 1846, the equity suit having been decided, they were authorized "to erect suitable monuments at the prominent angles of the line, from the Atlantic Ocean to the northwest corner of Rhode Island, and at such other points on the line as may subserve the public convenience." A majority of said commissioners agreed upon a line and erected monuments in 1847.

The report of the joint commission was dated Boston, January 13, 1848.

The line so agreed upon as a boundary between Burnt Swamp Corner and the northwest corner of Rhode Island was a straight line, varying a little from the irregular jurisdictional line established by the decision of the Supreme Court, and is described in the joint report of the majority of the commissioners of January, 1848, as follows, viz :

Begin at the northwest corner of Rhode Island, on Connecticut line, in latitude $42^{\circ} 00' 29''$ north, and longitude $71^{\circ} 48' 18''$ west of Greenwich, thence easterly in a straight line 21.512 miles to Burnt Swamp Corner, in Wrentham, being in latitude $42^{\circ} 01' 08''$ and longitude $71^{\circ} 23' 13''$.

Upon this line were placed twenty-seven monuments, exclusive of that at Burnt Swamp Corner.

The general assembly of Rhode Island, in May, 1847, ratified and established the line from the ocean to the Connecticut line, "to take effect and become binding whenever the said agreement and boundary line should be ratified by the State of Massachusetts." The legislature of Massachusetts did not ratify the said agreement and boundary line, but proposed another joint commission, which was agreed to.

The attempt made by these commissioners to settle the line having failed, Massachusetts commenced a bill in equity before the Supreme Court of the United States for an adjudication of the boundary line from Burnt Swamp Corner to the Atlantic Ocean.

In 1860 both States agreed upon a conventional line, and asked that a decree of the United States Supreme Court should confirm the same, which prayer was granted, and the line was thus finally established by a decree rendered in the December term, 1861, which is as follows, viz:

Beginning at Burnt Swamp Corner (so called), in Wrentham, in latitude $42^{\circ} 01' 08''$ north, longitude $71^{\circ} 23' 13''$ west of Greenwich, being the northeasterly corner of Rhode Island.

Thence in a straight line to the center of a stone monument in the division line, between Attleborough and Pawtucket, on the easterly bank of the Blackstone River, being in latitude $41^{\circ} 53' 36''$ north, longitude $71^{\circ} 23' 14''$ west.

Thence easterly, by the northerly line of the town of Pawtucket, to a point where said line intersects the highest water mark on the easterly side of Farmer's or Seven Mile River, which point is shown on accompanying sheet marked "A," and designated as "Bound No. 1," being in latitude $41^{\circ} 53' 54''$ north, longitude $71^{\circ} 20' 40''$ west.

From Bound No. 1 the line runs southerly, following the highest water mark on the easterly side of Farmer's or Seven Mile River, as designated in said sheet marked "A," to its junction with the highest water mark on the southerly and easterly side of Ten Mile River, at a point designated as "Bound No. 3."

From Bound No. 3 the line runs southerly, following the highest water mark on the southerly and easterly side of said Ten Mile River, as shown on sheet marked "A," to a point designated as "Bound No. 13," said last point being at the most southerly bend of Ten Mile River in said line of highest water mark.

The line of "highest water mark" as shown on sheet A is defined by offsets at right angles to straight lines shown on said plan in blue ink, from Bound No. 1, and passing through points designated as bounds numbered 2 to 13, inclusive.

From Bound No. 13 the line runs southeasterly, being a straight line to the center of a stone pier in the middle of Runnin's River, on the north side of the road leading by Luther's store.

Thence through the center or middle of said Runnin's River as the same is at low water at a point when such line intersects the dividing line between Barrington and Seekonk, being in latitude $41^{\circ} 46' 28''$, longitude $71^{\circ} 19' 23''$.

Thence northeasterly, following the dividing line between Barrington and Seekonk, to a point at the northerly extremity of the dividing line between Barrington and Swanzy, in latitude $41^{\circ} 36' 34''$, longitude $71^{\circ} 19' 30''$.

Thence in a straight line southeasterly to the center of a copper bolt in King's Rock, so called and well known, near an ancient monument on said King's Rock, being on the west side of the road leading from Warren to Swanzy. This point is in latitude $41^{\circ} 45' 22''.98$, longitude $71^{\circ} 16' 35''.75$.

From King's Rock the line follows the dividing line between Warren and Swanzy to Mount Hope Bay, running in a straight line southeasterly to a point on the Birch Swamp Farm, in latitude $41^{\circ} 45' 08''$, longitude $71^{\circ} 15' 58''.5$.

Thence in a straight line to Mount Hope Bay, passing through the center of a copper bolt in a boulder, in line of extreme high water at Toweset, to low-water line of said bay. This bolt is in latitude $41^{\circ} 42' 45''.27$, longitude $71^{\circ} 13' 54''.70$.

From Toweset the line runs southeasterly, crossing Mount Hope Bay, to the westerly end of line dividing Fall River and Tiverton, where the same intersects low-water line of said Mount Hope Bay.

Thence easterly, following said dividing line between Fall River and Tiverton, passing through the middle of a town way on the north side of farm belonging to John Chase, and through the southerly end of Cool's Pond, in a line passing through the middle of a highway, eight rods wide.

Thence running southerly through the center of said eight-rod highway to a point in line with the stone wall on northerly side of farm of Edmund Estes. This wall is easterly of the Stafford road (so called.)

Thence running easterly in line with said wall to a point in line of highest water mark on the westerly shore of South Watuppa Pond, which point is shown on accompanying sheet marked "B," and designated as "Bound A."

From Bound A the line runs southerly, following the highest water mark on westerly side of South Watuppa Pond, and of Sawdy Pond, and of the streams connecting said ponds, as shown on said sheet marked "B," to a point designated as "Bound F," said last point being at the most southerly end of Sawdy Pond in said line of highest water mark.

The line of "highest water mark" as shown on sheet B is defined by offsets at right angles to straight lines from Bound A, and passing respectively through points designated "B" to "F," inclusive, and on the South Watuppa Pond is also the line that would be traced by a level thirteen inches above a bolt in stone work on westerly side of waterway in gate-house of reservoir dam of Watuppa Reservoir Company, Quequechan River. On Sawdy Pond the highest water mark is the line that would be traced by the level of an iron bolt driven in west side of flume to saw-mill at northerly end of said Sawdy Pond.

From Bound F the line runs southeasterly, being a straight line to the monument known as "Joe Sanford's bound," being the center of a copper bolt in stone on land of Joseph Tripp, and is in latitude $41^{\circ} 35' 37''$ longitude $71^{\circ} 08' 13''$.

From Joe Sanford's bound the line runs southerly, following the westerly line of the town of Westport to the Atlantic Ocean, passing easterly of Quicksand Pond through the center of a bound known as Peaked Rock, situated in latitude $41^{\circ} 29' 58''$, longitude $71^{\circ} 07' 34''$.

The first point in this line southerly of Sanford's bound is on the north side of mill-dam at Adamsville, 85.58 feet easterly of straight line from Sanford's to Peaked Rock.

The second is 113.94 feet easterly of said straight line, and is on the easterly side of road leading from Adamsville to the ocean.

The third is 234.48 feet east of said straight line, on the road leading to Little Compton, by Philip Simmons' house.

The whole of the line thus described is shown on a plan herewith presented, which, with Sketches A and B, is made a part of this report and attested.

It will be observed that the above decree of the United States Supreme Court makes no reference to the line from Burnt Swamp Corner to the Connecticut line.

It will also be remembered (*vide* p. 55) that the "line of 1848," so called, was ratified by Rhode Island and rejected by Massachusetts. In 1865 the legislature of Massachusetts took action in regard to this portion of the line, as follows, viz :

Resolved, That the boundary line between the State of Rhode Island and the Commonwealth of Massachusetts, from the line of the State of Connecticut to Burnt Swamp Corner, begins at the northwest corner of the State of Rhode Island on the Connecticut line, in latitude $42^{\circ} 00' 29''$ north, and longitude $74^{\circ} 48' 18''$ west of Greenwich,³ and runs in a straight line 21 and $\frac{11}{16}$ miles to Burnt Swamp Corner, in Wrentham, being in latitude $42^{\circ} 1' 8''$ and longitude $71^{\circ} 23' 13''$.

This is the line agreed upon by the commissioners, called the "line of 1848," ratified at the time by Rhode Island, but rejected by Massachusetts.

The tardy ratification of the line by Massachusetts was, in its turn,

³ This is a clerical error. "Longitude $74^{\circ} 48' 18''$ " should read "longitude $71^{\circ} 43' 18''$." (*Vide* Borden's Tables, p. 64).

rejected by Rhode Island, on the ground that the then recent settlement of the eastern boundary by the decree of the Supreme Court had so changed the aspect of the controversy that she could not consent to the adoption of the line of 1848 as her northern boundary.

Thus the northern boundary of Rhode Island was left in abeyance, or rather left in the condition prescribed by the decision of 1846.

In June, 1880, the legislature of Rhode Island passed a resolution to remove the monuments of the "line of 1848" and erect monuments on the jurisdictional line.

In 1881 the legislature of Massachusetts took like action.

This jurisdictional line has the same termini as the line of 1848, but is a very irregular line, sometimes running north of a direct line and sometimes falling south of it [the extreme variations being 529.3 feet north of the line of 1848, and 129 feet south of the same.] A full and detailed description may be found in Rhode Island acts, May, 1867, p. 6 *et seq.*

Also, *vide* Senate Document No. 14, Massachusetts, 1848, for a full account of this controversy.

In 1713, commissioners from the Province of Massachusetts Bay and Colony of Connecticut settled a line between Massachusetts and Connecticut.

By this line certain northern frontier towns were given to Massachusetts, viz: Woodstock, Suffield, Enfield, and Somers. In 1749 the legislature of Connecticut passed a resolution that, inasmuch as the line had not been approved by the King, and that the two colonies had no legal right to transfer territory without the confirmation of the Crown, the contract was void, and these towns were again taken under the jurisdiction of Connecticut. Massachusetts appealed to the King, and the claims of Connecticut were fully established. (See Hollister's History of Connecticut, Vol. II.)

In 1791 Massachusetts and Connecticut appointed commissioners to establish the boundary between them, but they were unable to agree.

In 1803 commissioners were appointed to complete the line, a compromise having been made concerning the line between the town of Southwick and the towns of Suffield and Granby (the cause of the disagreement of the former commissioners).

The agreement made was as follows, viz:

That the line should begin from a station 8 rods south of the southwest corner of West Springfield, and thence run west to the large ponds, and thence southerly by those ponds to the ancient south line of Westfield, and from thence on said south line to the ancient southwest corner of Westfield; and from thence northerly in the ancient west line of Westfield to the station in said west line made by commissioners in the year 1714, and from thence to the southwest corner of Granville. (See Mass. Special Laws, Vol. III, page 234.)

In 1803 the commissioners surveyed and marked the boundary between their respective States.

Their report, which was adopted, is as follows, viz :

Beginning at the northeast corner of Suffield and the southeast corner of West Springfield, on the west bank of Connecticut River, at a point 75 links northward of the center of a small valley running into said river, said point being between a small butternut tree, marked M. C., standing on the south, and a small crooked white oak, marked M., standing on the north, about two feet distant from each other, and then run north $82^{\circ} 45'$ west 1 chain to a stone monument erected by us there; in the same course 22 chains 25 links to a stone monument on the stage road from Springfield to Suffield, and said course continued would pass two feet north of Smith's house; thence north 82° west 82 chains 3 links to a stone monument on the middle road from Suffield to Springfield; then in the same course 13 chains 30 links to a large black or red oak tree, marked on the east side C., and on the west side M., being an ancient bound; thence north $77^{\circ} 4'$ west 134 chains 42 links to a stone monument on the road from Feeding Hills meeting-house to Suffield; thence in the same course 4 chains 21 links to a pine stump—an old monument; thence north $79^{\circ} 48'$ west 102 chains 80 links to a stone monument on the road from Westfield to Suffield, called the back street; thence north $81^{\circ} 30'$ west 61 chains 20 links to a stone monument at an old stump and stones, the ancient southwest corner of West Springfield; thence south 5° west 2 chains to a stone monument in the line run by commissioners in 1714; thence north 85° west 167 chains 33 links to a stone monument at the middle pond, 22 links east of low-water mark, being at the center of a little valley running into said pond; thence on the eastern shore of said pond, as the same runs southerly, to a sluice way or outlet from said pond to the south pond; thence southerly on the east shore of the south pond as the same runs to a stone monument at high-water mark on the south corner of said pond, being the south end of the most southerly bay thereof, from which the point of land beyond the bay on the east side of the pond bears north 29° east, and the high point beyond the bay on the west side of the pond is north $3^{\circ} 30'$ east; then south $10^{\circ} 20'$ west 24 chains 78 links to a stone monument at the southeast corner of Southwick, in the ancient south line of Westfield, from which the highest peak of Manatick Mountain bears south $42^{\circ} 30'$ west; thence south $67^{\circ} 30'$ west 33 chains 86 links to a heap of stones in a hedge, being an ancient monument in the south line of Westfield and the north-west corner of Suffield, adjoining Granby; thence in said ancient south line of Westfield the same course to a stone monument at a white oak stump, an old monument, the southwest corner of Southwick, being 174 chains 36 links; thence north $10^{\circ} 20'$ east 212 chains 84 links to a stone monument erected by us, at a place in the ancient west line of Westfield, where commissioners in 1714 established the monument called the Crank monument; thence north $82^{\circ} 17'$ west 137 chains to a stone monument erected by us at the east road from Granby to Granville; in this course, at the distance of 86 chains 20 links from the Crank monument, we passed between two pillars of stones 45 links south of one and 13 links north of the other, both said to be the southeast corner of Granville; thence on the same course 61 chains 40 links to a stone monument erected by us on the Granby turnpike road; thence in the same course 44 chains to a white-oak tree, marked by commissioners in 1717, and which we marked M on the north side and C, 1803, on the south side; thence north $84^{\circ} 24'$ west 5 chains 13 links to a stone monument erected by us on the west road from Granby to Granville; thence in the same course 200 chains 37 links to a white elm stump and stones on the west bank of Valley Brook, so-called, a monument, made by commissioners in 1717 in this course three monuments are mentioned by said commissioners, which we do not find; thence north $85^{\circ} 7'$ west 60 chains 15 links to a stone monument erected by us at a new road near the east bank of Hubbard River; thence the same course 2 chains to dry hemlock tree with stones about it on the west side of said river near a small fall and a rock on the east side of said river stooping towards it more than 2

*Oak-tree boundary at Granville, marked in 1717.

rods to a monument erected by said former commissioners; thence north $82^{\circ} 52'$ west 109 chains 35 links to a stone monument^a erected by us on the road from Granville to Hartland; thence the same course 275 chains 91 links to a large heap of stones on the west bank of Slocum Brook between two hemlock trees, having many ancient and modern marks thereon, being a monument made by said former commissioners; in this course, the commissioners of 1717 made mention of a large hemlock tree, and a very large white-ash tree which we do not find; thence north $81^{\circ} 50'$ west 93 chains 74 links to a stone monument erected by us on the Beach-hill Road, so-called; thence in the same course 235 chains to a stone monument erected by us at a heap of stones about an elm tree standing on the west bank of Sandy Brook, a monument made by said former commissioners, who mentioned in their report a monument in this course, which we do not find; thence north $82^{\circ} 11'$ west 357 chains 30 links to a stone monument erected by us on the road from Marlborough to Norfolk; thence same course 38 chains 20 links to a monument made by said former commissioners on the west bank of Whiting River, near falls, being a heap of flat stones on a large rock; thence north $82^{\circ} 9'$ west 219 chains to a stone monument at the end of Greenwood Turnpike road; in this course said former commissioners marked two trees, which we do not find; thence in the same course 161 chains 75 links to a stone monument at the Burrell Road, so-called, leading from Canaan to Suffield; thence in the same course 49 chains to an elm tree, with stones near it, on the east bank of Housatonic River, about six rods west from a chestnut stump and stones, a monument made by said former commissioners, who also marked a white oak tree in this course which we not find; thence north $82^{\circ} 52'$ west 20 chains 50 links to a stone monument erected by us at the road leading from Salisbury to Sheffield, called Wetany Road; thence in the same course 119 chains 50 links to a stone monument erected by us at the road from Salisbury to Sheffield, near Ebenezer Fletcher's house; thence on the same course 211 chains 35 links to a stone monument erected by us at the mountain road from Salisbury to Sheffield; thence on the same course 28 chains 4 links to a monument established by said former commissioners at the foot of the mountain, being a heap of stones on a large rock, 20 links long on the northeasterly side, 5 feet high on the southerly side, and which we marked 1803 on the southerly side; thence north $85^{\circ} 30'$ west 147 chains 20 links to a stone monument erected by us on the road from Salisbury to Mount Washington; thence on the same course 81 chains 80 links, to a large heap of stones, the oblong corner bounds, so-called between the State of Connecticut and New York.

The courses of said line as before given, and here by us are according to the present state of Magnetic needle, which we observed to vary 5° west of north. (See Private Laws of Conn., vol. 2, pages 1540 to 1544.)

ABSTRACT OF REPORT OF COMMISSION OF 1803 ON BOUNDARY BETWEEN MASSACHUSETTS AND CONNECTICUT WEST OF THE CONNECTICUT RIVER.

Beginning at a point on the west bank of Connecticut River, in latitude $42^{\circ} 01' 52''$.10, longitude $72^{\circ} 37' 03''$.46, and running north $82^{\circ} 45'$ west 22 chains 25 links; thence north 82° west 95 chains 33 links; thence north $77^{\circ} 4'$ west 138 chains 63 links; thence north $79^{\circ} 48'$ west 102 chains 80 links; thence north $81^{\circ} 30'$ west 61 chains 20 links; thence south 5° west 2 chains; thence north 85° west 167 chains 33 links to a stone monument at the middle pond, 22 links east of low-water mark, latitude $42^{\circ} 02' 11''$, longitude $72^{\circ} 45' 45''$.07; thence southerly along the east shore of said pond, and also south pond, to a stone monument at high-water mark, at the south corner of said south pond; thence south $10^{\circ} 20'$ west 24 chains 78 links to a stone monument at southeast corner of Southwick, which is in latitude $42^{\circ} 00' 11''$.93, lon-

^a Boundary stone in west front of Granville.

gitude $72^{\circ} 46' 24''.23$; thence south $87^{\circ} 30'$ west 208 chains 22 links to a stone monument at the southwest corner of Southwick, which is in latitude $41^{\circ} 59' 51''.89$, longitude $72^{\circ} 49' 25''.47$; thence north $10^{\circ} 20'$ east 212 chains 84 links, to a stone monument at the northwest corner of the Southwick Jog, which is in latitude $42^{\circ} 02' 12''.39$, longitude $72^{\circ} 49' 13''.51$; thence north $82^{\circ} 17'$ west 242 chains 40 links to a white oak tree, marked by commissioners in 1717, which is in latitude $42^{\circ} 02' 15''.84$, longitude $72^{\circ} 52' 47''.74$; thence north $84^{\circ} 24'$ west 205 chains 50 links; thence north $85^{\circ} 7'$ west 62 chains 15 links; thence north $82^{\circ} 52'$ west 109 chains 35 links to a stone monument in latitude $42^{\circ} 02' 17''.03$, longitude $72^{\circ} 58' 22''.52$; thence north $82^{\circ} 52'$ west 275 chains 91 links; thence north $81^{\circ} 45'$ west 70 chains; thence north $81^{\circ} 50'$ west 328 chains 74 links to a stone monument, which is in latitude $42^{\circ} 02' 31''.11$, longitude $73^{\circ} 07' 35''.94$; thence north $82^{\circ} 11'$ west 395 chains 50 links; thence north $82^{\circ} 9'$ west 430 chains; thence north $82^{\circ} 52'$ west 140 chains to a stone monument on the road from Salisbury to Sheffield, which is in latitude $42^{\circ} 02' 58''.11$, longitude $73^{\circ} 22' 55''.27$; thence north $82^{\circ} 52'$ west 239 chains 39 links; thence north $85^{\circ} 30'$ west 239 chains to the northwest corner of Connecticut, which is in latitude $42^{\circ} 02' 58''.54$, longitude $73^{\circ} 30' 06''.66$.

According to the survey of the cession of Boston Corners, by Massachusetts to New York, in 1855, the south boundary of Massachusetts from the northwest corner of Connecticut to the southwest corner of Massachusetts is as follows, viz:

A line running north $89^{\circ} 08' 4''$ west, 40 chains, by the true meridian.

The courses of the line of 1803 are magnetic, with the variation as at that date: i. e., 5° west.

The latitudes and longitudes in the foregoing are taken from the Borden Trigonometrical Survey of Massachusetts of 1843.

In 1826, the line between Massachusetts and Connecticut east of the Connecticut River was run by commissioners appointed from each State. An abstract of the commissioners' report is here given:

Abstract of report of commissioners of 1826.—The commissioners first made the following survey: Commencing at the northeast corner of Connecticut, at a large pile of stones erected by commissioners of 1734; thence running due west on the latitude of $42^{\circ} 3'$ north to the west line of Woodstock, 15 miles 169 rods 15 links. (This is hereafter referred to as the "first line of latitude.") Thence north 3° west 54 rods 19 links to an old pine tree, the reputed northeast corner of Union; thence due west 25 miles 168 rods to Connecticut River. (This line is hereinafter referred to as the "second line of latitude," and the second line of latitude is 54 rods north of the first.) These lines of latitude were compared with the ancient survey, monuments, evidence, etc., of the line run by the commissioners of 1713; the said lines of latitude were found to vary in sundry places therefrom. Therefore, in order to conform as near as possible to the line of 1713, the line was run as follows, viz:

Beginning at the northeast corner of Connecticut and running west on "first line of latitude" 1,702 rods and 4 links to the road to the Merino road; thence in a direct line 1,372 rods 20 links to the road leading from Muddy Brook, so called, by Pennel May's to Southbridge; this point is 21 rods 10 links north of the "first line of latitude"; thence in a direct

line 360 rods 5 links to the Norwich and Woodstock turnpike (this point is 20 rods and 5 links north of "first line of latitude"); thence in a direct line 954 rods 18 links to the road leading from West Woodstock by Abel Mason's to Southbridge (this point is 10 rods and 22 links north of "first line of latitude"); thence in a direct line 1,247 rods to the road leading from Union by Asher Bodgen's to Holland (this point is 2 rods 14½ links south of "second line of latitude"); thence in a direct line 1,127 rods to the turnpike from Hartford through Stafford and Holland to Worcester (this point is 6 rods 23½ links south of the "second line of latitude"); thence in a direct line 467 rods to an old white-oak tree, an ancient bound, on the road from Stafford by Robert Andruss' to South Brimfield (this point is 1 rod 2 links south of "second line of latitude"); thence in a direct line of 1,615 rods to the road leading from Stafford by Henry Cady's to Monson (this point is 16 rods 15 links south of "second line of latitude"); thence in a direct line 256 rods to the Tracy road (this point is 12 rods 12 links south of "second line of latitude"); thence in a direct line 620 rods to the road leading from Stafford by Seth Sheldon's to South Wilbraham (this point is 14 rods 7 links south of "second line of latitude"); thence in a direct line 1,066 rods to the road from Somer's by Walter Ainsworth's to Springfield (this point is 4 rods 1 link north of "second line of latitude"); thence in a direct line 523 rods to the road from Somer's by Abel Peas's to Springfield (this point is 6 rods 12 links south of the "second line of latitude"); thence *due west* 645 rods to the ancient line between Springfield (now Long Meadow) and Enfield; thence *south* 80° 30' *west* by the true meridian 645 rods to a monument at an old oak stump; thence *south* 51° 30' *west* by the true meridian 164 rods 18 links to a monument at an old pine stump; thence *due west* 349 rods 15 links to a monument on the Connecticut River 12 rods from the shore; thence *due west* to Connecticut River. On the line are erected 49 monument stones, marked on the north side M and on the south side C.

The commissioners also surveyed and marked the line from the the corner of Connecticut to the corner of Rhode Island, reporting as follows:

Beginning at the monument erected at the northeast corner of said State of Connecticut and running in a direct line to the ancient heap of stones on the north side of the turnpike leading from Hartford to Boston through Thompson and Douglass, where we erected a monument, and thence running in a direct line to the northwest corner of the State of Rhode Island.

(For survey of 1826, see Private Laws of Conn., vol. 2, pages 1544 to 1550.)

The boundary between Massachusetts and New York at an early period became a subject of bitter dispute, New York claiming to the west bank of the Connecticut River under the charters of 1664 and 1674 to the Duke of York, Massachusetts claiming under her old charters to the South Sea. After many fruitless attempts at a settlement, an ar-

rangement was entered into in 1773 fixing the western boundary of Massachusetts where it meets New York territory. The Revolution following soon after, the line was not run. In 1785 Congress appointed three commissioners to run the line, who performed that duty in 1787. The line was as follows, viz:

Beginning at a monument erected in 1731 by commissioners from Connecticut and New York, distant from the Hudson River 20 miles, and running north $15^{\circ} 12' 9''$, east 50 miles 41 chains and 79 links, to a red or black oak tree marked by said commissioners, which said line was run as the magnetic needle pointed in 1787. (*Vide Revised Statutes of New York, 1875, p. 122.*)

The claims of Massachusetts to western lands were finally settled December 16, 1786, by a joint commission of the two States. By this agreement Massachusetts surrendered the sovereignty of the whole disputed territory to New York, and received in return the right of soil and pre-emption right of Indian purchase west of the meridian passing through the eighty-second mile-stone of the Pennsylvania line, excepting certain reservations upon Niagara River. The title to a tract known as "The Boston Ten Towns," lying east of this meridian, previously granted by Massachusetts, was also confirmed. (*Vide Hough's N. Y. Gaz., 1872, pp. 25, 26.*)

April 19, 1785, Massachusetts executed a deed to the United States. It included all title of the State of Massachusetts to territory west of the present western boundary of New York.

In 1820 Maine, hitherto a part of Massachusetts, was admitted into the Union as an independent State.

In 1853 a small portion of territory in the southwestern corner of Massachusetts, known as Boston Corner, was ceded to New York, and the cession confirmed by Congress in 1855.

The cession of Boston Corner to New York changes the boundary, so that it is now as follows, viz:

Beginning at a monument erected in 1731 by commissioners from Connecticut and New York (known as the Connecticut monument), standing in the south boundary of Massachusetts, latitude $42^{\circ} 02' 58''.54$, longitude $73^{\circ} 30' 06''.66$, which is the northwest corner of the State of Connecticut; thence along the south boundary of Massachusetts, north $89^{\circ} 08' 41''$ west, 40 chains; thence north $12^{\circ} 57' 16''$ west 207.49^s chains to a marble post marked on the east side M. S., on the west side N. Y., and on the south side 1853, which is in the line run by United States commissioners in 1787; thence north $15^{\circ} 12' 9''$ east on the line run by said United States commissioners (647 miles 73.70^s chains) to a red or black oak tree marked by said United States commissioners, in the south boundary of the State of Vermont, latitude $42^{\circ} 44'$

*This distance has been obtained by subtracting the length of the west line of Boston Corner given in survey of 1853 from the entire length of west boundary of Massachusetts as given by the United States commissioners in 1787.

45'' 58, longitude 73° 16' 17'' 68. [See Revised Statutes of New York, 1875, page 122; also plat of survey of Boston Corner in 1853, a copy of which is on file in office of clerk of House of Representatives at Washington, D. C.; also, for latitudes and longitudes, see tables of Borden's Survey of Massachusetts, 1843.]

Latitude and longitude of certain points on the boundary line of Massachusetts. (From Borden's Trigonometrical Survey, 1843.)

States.	Stations.	Latitude.	Longitude.
		° ' "	° ' "
Vermont and Massachusetts.	Northwest corner	42 44 45.58	73 16 17.63
	Rowe and Whittingham Station in Vermont line	42 44 18.48	72 53 07.95
New Hampshire and Massachusetts.	Leyden and Guilford Station in Vermont line ..	42 43 55.78	72 38 46.57
	Warwick (N. H.) State line station	42 43 22.01	72 19 35.32
	Watfick State line station in Ashburnham (Mass.) ..	42 42 41.56	71 54 15.84
	Pepperell (N. H.) State line station	42 42 13.22	71 35 32.02
	Pine Tree boundary, State line at Dracut (Mass.) ..	42 41 50.78	71 19 40.59
	Poplar Hill State line boundary, New Hampshire line at Methuen ..	42 44 12.00	71 15 38.72
Connecticut and Massachusetts.	Ayres Hill State line boundary at Haverhill, Mass.	42 48 23.88	71 04 11.68
	Brandy Brow Hill, State line corners of Haverhill and Amesbury, Mass.	42 50 00.61	71 03 34.17
	Salisbury Marsh Station	42 52 19.32	70 49 32.11
	Southwest corner of Massachusetts	42 02 59.54	73 31 42.66
	Connecticut line bound at Mount Washington ..	42 02 58.54	73 30 06.66
	Boundary stone in Connecticut line on road from Sheffield to Salisbury ..	42 02 58.11	73 22 55.27
	Boundary stone in Connecticut line on road from Sandisfield to Colchbrook ..	42 02 31.11	73 07 35.94
	Boundary stone in Granville, in west part of town ..	42 02 17.03	72 58 22.52
	Oak tree boundary in Connecticut State line at Granville, marked in 1717 ..	42 02 15.84	72 52 47.44
	Boundary stone at northwest corner of Southwick Jog.	43 02 12.39	72 49 13.51
	Boundary stone at southwest corner of Southwick Jog.	41 59 51.89	72 49 25.47
	Boundary stone at southeast corner of Southwick Jog.	42 00 11.98	72 46 24.23
	Boundary stone at northeast corner of Southwick Jog.	42 02 11.00	72 45 45.07
	Boundary stone in Connecticut line on west side of Connecticut River ..	42 01 52.10	72 37 03.46
	Boundary stone in Connecticut line on east side of Connecticut River ..	42 01 28.74	72 36 36.31
	Rattlesnake Mountain in Connecticut line at Wilbraham ..	42 01 59.66	72 24 49.86
	High Rocky Ridge, Connecticut line, in Monson ..	42 01 56.09	72 21 07.26
	Monson line station in Monson	42 01 53.92	72 16 39.28
	Northeast corner of Connecticut at Douglas ..	42 01 25.21	71 48 23.66
Rhode Island and Massachusetts.	Northwest corner of Rhode Island at Douglas ..	42 00 29.43	71 43 18.07
	Burnt Swamp corner, northeast corner of Rhode Island ..	42 01 08.60	71 23 13.26
	Munroe's Station, Rhode Island State line at Seekonk ..	41 46 34.54	71 19 22.92
	Kings Rock Station, Rhode Island State line at Warren ..	41 45 22.98	71 16 35.75
	Toweset Neck Station, in Rhode Island, State line at Swanzy ..	41 42 45.27	71 13 54.70
	Joe Sandford's Station, Rhode Island State line at Tiverton ..	41 35 37.66	71 08 12.78
	Quicksand Pond, State line boundary stone in Rhode Island line at Westport ..	41 29 58.64	71 07 34.38

These positions require a correction of from 15'' to 20'' in order to make them conform to modern determinations of position.

*This corner was changed by the cession of Boston Corner by Massachusetts to New York in 1855.

RHODE ISLAND.

The present State of Rhode Island was settled by Roger Williams and other immigrants, who left Massachusetts Bay and established themselves at Providence in 1636.

In 1643 a patent was granted for the Providence Plantation, from which the following are extracts, viz:

* * * * *

And whereas there is a tract of land in the continent of America aforesaid, called by the name of the Narraganset Bay, bordering northward and northeast on the patent of the Massachusetts, east and southeast on Plymouth patent, south on the ocean, and on the west and northwest by the Indians called Narigganneucks, alias Narragansets, the whole tract extending about 25 English miles unto the Pequot River and country; and whereas divers English inhabitants of the towns of Providence, Portsmouth, and Newport, in the tract aforesaid, * * * have represented their desire, * * * we * * * do * * * give, grant, and confirm to the aforesaid inhabitants of the towns of Providence, Portsmouth, and Newport a firm and absolute charter of incorporation, to be known by the name of the incorporation of Providence Plantations, in the Narraganset Bay, in New England. * * *

In 1663 Charles II granted a charter to Rhode Island and Providence Plantations, of which the following is an extract:

* * * "All that parte of our dominiones in New-England, in America, conteyneing the Nahantick and Narragansett Bay, and countreyes and partes adjacent, bounded on the west, or westerly, to the middle or channel of a river there, commonly called and known by the name of Pawcatuck, alias Pawcawtuck river, and soe along the sayd river, as the greater or middle streame thereof reacheth or lyes upp into the north countrey, northward, unto the head thereof, and from thence, by a streight lyne drawn due north untill itt meets with the south lyne of the Massachusetts Collony; and on the north, or northerly, by the aforesayd south or southerly lyne of the Massachusetts Collony or Plantation, and extending towards the east, or eastwardly, three English miles to the east and north-east of the most eastern and north-eastern parts of the aforesayd Narragansett Bay, as the sayd bay lyeth or extendeth itself from the ocean on the south, or southwardly, unto the mouth of the river which runneth towards the towne of Providence, and from thence along the eastwardly side or banke of the sayd river (higher called by the name of Seacunck river), up to the falls called Patuckett falls, being the most westwardly lyne of Plymouth Collony, and soe from the sayd falls, in a streight lyne, due north, untill itt meet with the aforesayd line of the Massachusetts Collony; and bounded on the south by the ocean." And in particular, the lands belonging to the townes of Providence, Pawtuxet, Worwicke, Nusquamack, alias Pawcatuck, and the rest upon the main land in the tract aforesayd together with Rhode Island, Blocke Island, and all the rest of the islands and banks in the Narragansett Bay and bordering upon the coast of the tracts aforesaid (Fishers Island only excepted). * * *

(For history of the northern and eastern boundaries see Massachusetts, p. 48.)

In 1703 substantially the present western boundary was settled by an agreement made between the commissioners from the two colonies of Rhode Island and Connecticut, viz: "A straight line from the mouth

(521)

of Ashawoga River to the southwest corner of the Warwick purchase, and thence a straight north line to Massachusetts.

The line of 1703 was actually run by Rhode Island, and is still known as the Dexter and Hopkins line.

The two colonies disagreeing, Rhode Island appealed to the King, and the agreement of 1703 was finally established in 1726.

In September, 1728, commissioners from the two colonies met and ran the line.

(For agreement of 1703 and 1728, decisions of English council, etc., see R. I. Hist. Soc. Coll., Vol. III.)

In 1830 commissioners were appointed by Rhode Island and Connecticut to survey and ascertain the line and erect monuments.

The following line was established, viz:

Beginning at a rock near the mouth of Ashawoga River, where it empties into Pawcatuck River, and from said rock a straight course northerly to an ancient stone heap at the southeast corner of the town of Voluntown, and from said rock southerly in the same course with the aforesaid line, until it strikes Pawcatuck River. From the southeast corner of Voluntown a straight line to a stone heap at the southwest corner of West Greenwich; from thence a straight line to the southwest corner of the ancient town of Warwick, and which is now a corner of the towns of Coventry and West Greenwich; from thence a straight line to the northwest corner of the town of Coventry; thence a straight line to the northeast corner of Sterling; thence a straight line to the southwest corner of Burrillville, and thence a straight line to a stone heap upon a hill in the present jurisdictional line between the States of Massachusetts and Rhode Island, and at all of said corners, excepting said Warwick corner, we have erected monuments of stone, marked R. I. and C., and have also placed similar monuments on all the principal roads crossing the line, and at other suitable places.

And we have caused the ancient monument which was erected at the Warwick corner in November, 1742, to be reset and a large heap of stones to be made around it. Said monument is marked with the letter C. on one side, and on the other R H O D E. I S L A N D and the traces of other letters and figures. [Extract from Commissioner's Report. See R. I. Acts and Resolves, Jan. 1846, pages 12, 13, 14.]

The above was ratified in 1846.

CONNECTICUT.

The title by which the people of Connecticut held the country was founded on the old patent granted by Robert, Earl of Warwick, in 1631, to Lord Say and Seal, Lord Brook, Sir Richard Saltonstall, and others, associated under the name of the Plymouth Company.

In 1630 the Plymouth Council made a grant of Connecticut to the Earl of Warwick, their president. This was confirmed by King Charles in 1631, and on the 19th of March, in the same year, the Earl conveyed his title to the Plymouth Company, as before stated. (Dwight's Conn., p. 19, *et seq.*)

A charter was granted by Charles II to Connecticut in 1662, of which the following is an extract, viz:

* * * * *

We * * * do give, grant and confirm unto the said Governor and Company, and their successors, all that part of our Dominions in New England in America bounded on the east by Narraganset River, commonly called Narraganset Bay, where the said river falleth into the sea, and on the north by the line of the Massachusetts plantation; and on the south by the sea; and longitude as the line of the Massachusetts Colony, running from east to west, that is to say, from the said Narragansett Bay on the east, to the south sea on the west part, with the islands thereunto adjoining. * *

[C. and C., p. 256-7.]

Previous to this time the two colonies of Connecticut and New Haven had continued separate, but under this charter they were united and the charter was accepted April 20, 1665. (C. and C., p. 252.)

The Duke of York having been granted a charter in 1664, by which the lands west of the Connecticut River were embraced in his jurisdiction, the question of boundary immediately arose.

About this time Col. Richard Nichols, George Cartwright, esq., Sir Robert Carr, and Samuel Maverick, esq., had been appointed commissioners by the King, and clothed with extraordinary powers, to determine all controversies in the colonies. The matter was referred to them, who, after a full hearing, determined that the southern boundary of Connecticut was the sea (Long Island Sound), and its western, Mamaroneck River, and a line drawn north-northwest from the head of salt water in it to Massachusetts. The territory south and west of these lines was declared to belong to the Duke of York. (*Vide* Dwight's Connecticut, pp. 159 *et seq.*)

This decision, in effect, decided upon a line 20 miles east of the Hudson River as the boundary, having for a starting point a place on Mamaroneck River.

In 1674 the Duke of York received a new charter in substantially the same terms as that of 1664. New controversies concerning jurisdiction led to a new agreement, by which it was stipulated that a tract of land on Long Island Sound, the bounds of which were described as containing 61,440 acres, should be permanently set off to Connecticut by New York on condition that the former, in exchange, should set off to New York a territory of like extent and of uniform width from the tract on the Sound to the south line of Massachusetts. This agreement was sanctioned by a royal ordinance of the King, and in 1684 the tract on the Sound was surveyed and set off to Connecticut.

The western boundary of Connecticut was run in 1685 by Major Gould, Mr. Barr, and Mr. Selleck, and ratified by both parties. (*Vide* Dwight's Connecticut, p. 199.)

For various reasons the survey of the equivalent lands was not made at that time.

In 1725 commissioners were appointed on both sides to fix the line,

this being the fifth set appointed for the same purpose, none of which had been able to come to an agreement.

The commissioners of 1725, however, entered into articles of agreement settling the manner of the survey. They, however, ran only the line bounding the tract on Long Island Sound.

For some cause action was then suspended until 1731, when the commissioners of 1725 surveyed and set off the oblong or equivalent territory to New York, defining and marking its boundary, which was to remain forever the dividing line between the respective States (then colonies). The line was substantially as at present, and is as follows, viz:

Beginning at Lyon's Point, in the mouth of a brook or river called Byram's River, where it falls into Long Island Sound, and running thence up along said river to a rock at the ancient road or wading-place in said river, which rock bears north twelve degrees and forty-five minutes east, five hundred and fifty rods from said point; then north twenty-three degrees and forty-five minutes west, two thousand two hundred and ninety-two rods; then east-northeast, thirteen miles and sixty-four rods, which lines were established in the year one thousand seven hundred and twenty-five, by Francis Harrison, Cadwaller Colden, and Isaac Hicks, commissioners on the part of the then province of New York, and Jonathan Law, Samuel Eells, Roger Walcott, John Copp, and Edmund Lewis, commissioners on the part of the then colony of Connecticut, and were run as the magnetic needle then pointed; then along an east-northeast continuation of the last-mentioned course, one mile, three-quarters of a mile, and twenty-one rods, to a monument erected in the year one thousand seven hundred and thirty-one by Cadwaller Colden, Gilbert Willett, Vincent Matthews, and Jacobus Bruyn, jr., commissioners on the part of said province, and Samuel Eells, Roger Walcott, and Edmund Lewis, commissioners on the part of said colony, which said monument is at the southeast corner of a tract known and distinguished as the oblong or equivalent lands; then north twenty-four degrees and thirty minutes west, until intersected by a line run by said last-mentioned commissioners, on a course south twelve degrees and thirty minutes west, from a monument erected by them in the south bounds of Massachusetts, which monument stands in a valley in the Taghkanick Mountains, one hundred and twenty-one rods eastward from a heap of stones in said bounds, on the top or ridge of the most westerly of said mountains; then north twelve degrees and thirty minutes east from a monument erected by said last-mentioned commissioners at said place of intersection, and standing on the north side of a hill, southeasterly from the easternmost end of the long pond, along the aforesaid line to the aforesaid monument erected in the south bounds of Massachusetts—being the northeast corner of the oblong. (See Revised Statutes of N. Y., 1881, Vol. I, pages 128-9.)

For more than a century no controversy arose, but subsequent to 1850 questions of jurisdiction were raised, and in 1855 Connecticut made a proposition for a new survey. Several sets of commissioners were appointed, but no agreement being reached, finally, in 1860, pursuant to an act of the legislature of New York, the line was run by the New York commissioners, Connecticut not being represented.

The first section of the act of the New York legislature is as follows, viz:

1. The commissioners appointed by the governor to ascertain the boundary line between the States of New York and Connecticut are hereby empowered and directed

to survey and mark, with suitable monuments, the said line between the two States as fixed by the survey of 1731.

The following is an abstract of the engineer's report of the line run under direction of the commissioners from New York and Connecticut in 1731, the Connecticut commissioners declining to be present or assist, viz:

Beginning at the northwest corner of Connecticut, at the monument erected by the commissioners of New York and Connecticut in 1731, latitude $42^{\circ} 02' 58''.54$, longitude $73^{\circ} 30' 06''.66$; thence south $11^{\circ} 20'$ west, 464 chains, to the 47th mile monument; thence south $12^{\circ} 34'$ west, 239 chains, 57 links, to the 44th mile monument point; thence south $11^{\circ} 33'$ west, 160 chains 99 links, to the 42d mile monument; thence south $13^{\circ} 16'$ west, 161 chains 24 links, to the 40th mile monument point; thence south $12^{\circ} 21'$ west, 398 chains 21 links, to the 35th mile monument; thence south $12^{\circ} 32'$ west, 158 chains 96 links, to the 33d mile monument; thence south $11^{\circ} 44'$ west, 243 chains 37 links, to the 30th mile monument; thence south $12^{\circ} 27'$ west, 161 chains 32 links, to the 28th mile monument; thence south $10^{\circ} 56'$ west, 160 chains, to the 26th mile monument point; thence south $11^{\circ} 39'$ west, 320 chains 11 links, to the 22d mile monument; thence south $12^{\circ} 18'$ west, 163 chains 17 links, to the 20th mile monument; thence south $11^{\circ} 49'$ west, 159 chains 9 links, to the 18th mile monument; thence south $12^{\circ} 19'$ west, 157 chains 15 links, to the 16th mile monument; thence south $10^{\circ} 11'$ west, 161 chains 7 links to the 14th mile monument; thence south $10^{\circ} 51'$ west, 313 chains 41 links, to the 10th mile monument point; thence south $12^{\circ} 24'$ west, 155 chains 71 links, to the 8th mile monument; thence south $10^{\circ} 19'$ west, 159 chains 28 links, to the 6th mile monument point; thence south $12^{\circ} 10'$ west, 164 chains 42 links, to the 4th mile monument; thence south $11^{\circ} 44'$ west, 158 chains 99 links, to the 2-mile monument; thence south $14^{\circ} 10'$ west, 109 chains 41 links, to the Ridgefield angle monument;* thence south $25^{\circ} 8'$ east, 213 chains 39 links, to the 4th mile monument on the east line of the oblong between the Wilton and Ridgefield angles; thence south $24^{\circ} 48'$ east, 157 chains 63 links, to the 2-mile monument; thence south $24^{\circ} 14'$ east, 167 chains 28 links, to the Wilton angle monument, or southeast corner of the oblong as set off by the commissioners of 1731; thence south $67^{\circ} 45'$ west, 138 chains 76 links, to the southwest corner of the oblong, and being where the survey of 1725 terminated; thence south $65^{\circ} 44'$ west, 90 chains 87 links, to a point considered the original 12th mile monument point; thence south $66^{\circ} 56'$ west, 241 chains 93 links, to a point called the 9th mile monument; thence south $66^{\circ} 45'$ west, 319 chains 12 links, to the 5th mile monument point; thence south $66^{\circ} 25'$ west, 398 chains 40 links, to the angle at the Duke's

*The mile monuments referred to are those, at that time remaining, which were established by the Connecticut and New York commissioners of 1731.

*The entire distance from the Massachusetts line to Ridgefield angle is 52 miles 35 rods, a difference of only 5 rods from the survey of 1731.

Trees; thence south $23^{\circ} 38'$ east, 172 chains 93 links, to a point which is west-southwest and distant 32 rods from the chimney in the old Clapp house; thence south $24^{\circ} 21'$ east, 224 chains 78 links, to a point opposite the old William Anderson house; thence south $24^{\circ} 19'$ east, 173 chains 7 links, to the great stone at the ancient wading place on Byrom River; thence south $17^{\circ} 45'$ west, 12 chains 60 links, to a rock in the river which can be seen at low tide, in which there is a bolt; thence south 27° west, 55 chains 19 links; thence south $7^{\circ} 20'$ east, 13 chains 45 links; thence south $12^{\circ} 10'$ east, 16 chains 13 links; thence south $2^{\circ} 40'$ east, 9 chains 4 links; thence south $28^{\circ} 25'$ east, 9 chains 54 links; thence south $18^{\circ} 40'$ east, 4 chains 77 links; thence south $11^{\circ} 55'$ west, 6 chains 33 links; thence south $58^{\circ} 10'$ west, to where it falls into the sound. (See report of the commissioners to ascertain and settle the boundary line between the States of New York and Connecticut, February 8, 1861, in which will also be found a complete account of this controversy.)

The latitude and longitude of the northwest corner of Connecticut are taken from Borden's Trigonometrical Survey of Massachusetts.

In 1880 commissioners were appointed by Connecticut and New York. Their report was ratified in 1880.

These commissioners reported as follows, viz :

We agree that the boundary on the land constituting the western boundary of Connecticut and the eastern boundary of New York shall be and is as the same was defined by monuments erected by commissioners appointed by the State of New York, and completed in the year 1860, the said boundary line extending from Byram Point, formerly called Lyon's Point, on the south, to the line of the State of Massachusetts on the north.

And we further agree that the boundary on the sound shall be and is as follows :

Beginning at a point in the center of the channel, about 600 feet south of the extreme rocks of Byram Point, marked No. 0, on appended United States Coast Survey chart; thence running in a true southeast course $3\frac{1}{4}$ statute miles; thence in a straight line (the arc of a great circle) northeasterly to a point 4 statute miles due south of New London Light-House; thence northeasterly to a point marked No. 1, on the annexed United States Coast Survey chart of Fisher's Island Sound, which point is on the longitude east three-quarters north, sailing course down on said map, and is about 1,000 feet northerly from the Hommock or North Dumping Light-House; thence following said east three-fourths north sailing course as laid down on said map, easterly to a point marked No. 2 on said map; thence southeasterly to a point marked No. 3 on said map; so far as said States are coterminous. (See Revised Statutes of New York, 1881, Vol., I, page 136.)

The above agreement concerning these boundaries between Connecticut and New York was confirmed by the Congress of the United States on February 26, 1881. (See Revised Statutes of United States, 1881.)

(For the history and present location of the eastern boundary of Connecticut, *vide* Massachusetts, p. 55, and Rhode Island, p. 65. For the northern boundary, *vide* Massachusetts, p. 58.)

Under the charter of 1662 Connecticut claimed a large western territory. Subsequent to the Revolution, however, in 1786, 1792, 1795, and 1800, she relinquished all title to any land west of her present boundary.

NEW YORK.

The territory included in the present State of New York was embraced in the French and English grants of 1603 and 1606. The Dutch, however, in 1613 established trading posts on the Hudson River and claimed jurisdiction over the territory between the Connecticut and Delaware Rivers, which they called New Netherlands. The government was vested in "The United New Netherland Company," chartered in 1616, and then in "The Dutch West India Company," chartered in 1621.

In 1664 King Charles II of England granted to his brother, the Duke of York, a large territory in America, which included, with other lands, all that tract lying between the west bank of the Connecticut River and the east bank of the Delaware. The Duke of York had previously purchased, in 1663, the grant of Long Island and other islands on the New England coast, made in 1635 to the Earl of Stirling, and in 1664, with an armed fleet, he took possession of New Amsterdam, which was thenceforth called New York. This conquest was confirmed by the treaty of Breda, in 1667.

The following is an extract from the grant of 1664 to the Duke of York:

All that parte of the maine land of New England beginning at a certaine place called or knowne by the name of St. Croix next adjoyning to New Scotland in America and from thence extending along the sea coast unto a certain place called Petuagwine or Pemaquid and so up the River thereof to the further head of ye same as it tendeth northwards and extending from thence to the River Kinebequi and so upwards by the shortest course to the River Canada northward and also all that Island or Islands commonly called by the severall name or names of Matowacks or Long Island scituate lying and being towards the west of Cape Codd and ye narrow Higansetts abutting upon the maine land between the two Rivers there called or knowne by the severall names of Conecticut and Hudsons River together also with the said river of Hudsons River and all the land from the west side of Conecticut to ye east side of Delaware Bay and also all those severall Islands called, or knowne by the names of Martin's Vinyard and Nantukes otherwise Nantuckett together with all ye lands islands soyles harbours mines minerals quarryes woods marshes waters lakes fishings hawking hunting and fflowling and all other royallties proffitts commodities and hereditaments to the said severale island lands and premisses belonging and appertaining with their and every of their appurtenances and all our estate right title interest benefitt advantage claime and demand of in or to the said lands and premisses or any part or parcell thereof and the revercon and reveroons remainder and remainders together with the yearly and other ye rents revenues and proffitts of all and singular the said premisses and of every part and parcell thereof to have and to hold all and singular the said lands islands hereditaments and premisses with their and every of their appurtenances.

In July, 1673, the Dutch recaptured New York and held it until it was restored to the English by the treaty of Westminster, in February, 1674.

The Duke of York thereupon, to perfect his title, obtained a new

grant, in substantially the same terms as that of 1664 (C. and C., p. 1328), of which the following is an extract, viz:

* * * * *

All that part of the main land of New England, beginning at a certain place called or known by the name of Saint Croix next adjoining to New Scotland in America, and from thence extending along the sea-coast into a certain place called Pettaquam or Pemquid, and so up the river thereof to the furthest head of the same as it windeth northward and extending from the river of Kinebequ and so upwards by the shortest course to the river Canada northwards; and all that island or islands commonly called by the several name or names of Matowacks or Long Islands, situate and being toward the west of Cape Cod and the narrow Higansuts abutting upon the main land between the two rivers there called or known by the several names of Connecticut and Hudson Rivers, together also with the said river called Hudson's River, and all the lands from the west side of Connecticut River to the east side of Delaware Bay; and also all those several islands called or known by the names of Martin Vineyard and Nantukes, otherwise Nantuckett.

* * * * *

By these grants to the Duke of York and the conquest of the Dutch possessions in America, it will be seen that New York originally had a claim to a much larger territory than is now included in her limits. The successive changes in her extent may be sketched as follows, viz:

In 1664 the Duke of York sold the present State of New Jersey to Lord John Berkeley and Sir George Carteret.

In 1682 the Duke of York sold to William Penn his title to Delaware and the country on the west bank of the Delaware, which had been originally settled by the Swedes, then conquered by the Dutch, and which had by them been surrendered to the Duke of York.

In 1686 Pemaquid and its dependencies were annexed to the New England government by a royal order, the Duke of York having acceded to the throne of England.

By the charter of 1691 to Massachusetts Bay, all claim to any part of Maine was extinguished, and the islands of Nantucket, Martha's Vineyard, and others adjacent (hitherto known as Duke's County, New York), were annexed to Massachusetts Bay.

The territory west of the Connecticut River to within about 20 miles of the Hudson River, now forming portion of Massachusetts and Connecticut, were, by agreements and concessions made at various periods, surrendered to those States respectively.

In 1781 New York released to the General Government all the lands to which she had claim west of a meridian extending through the west extremity of Lake Ontario, and in 1790 she gave up all claim to the present State of Vermont and consented to her independence.

By these successive reductions New York was left with substantially her present boundaries.

(For the history and settlement of the eastern boundary of New York, *vide* Vermont, Massachusetts, and Connecticut, *ante* pp. 46, 62, and 67.)

The northern boundary was settled by the treaty of peace in 1783

and by the commission under the sixth article of the treaty of Ghent. (*Vide* pp. 10 and 12.)

The boundary between New York and New Jersey was plainly stated in the grant by the Duke of York to Berkeley and Carteret. (*Vide* New Jersey, p. 76.)

In 1719 attempts were made to have the line run and marked, but nothing seems to have been done to settle the matter permanently till 1769, when commissioners were appointed by the King, who fixed on substantially the present line. (*Vide* R. S. N. J., 1821, pp. 29-34.)

In 1772 this line was confirmed by the legislatures of both colonies, and commissioners were appointed to survey and mark the same.

This line was as follows, viz :

A direct and straight line from the fork or branch formed by the junction of the stream or waters called the Machackamack with the river Delaware or Fishkill, in the latitude of $41^{\circ} 21' 37''$, to a rock on the west side of the Hudson River, marked by the said surveyors in the latitude of 41° —said rock was ordered to be marked—with the following words and figures, viz: "Latitude 41° north;" and on the south side thereof "New Jersey"; and on the north side thereof "New York"; also, to mark every tree that stood on the line with five notches and a blaze on the northwest and southeast sides thereof, and to put up stone monuments, at 1 mile distance from each other, along the said line, and to number such monuments with the number of miles; the same shall be from the before-mentioned marked rock on the west side of Hudson's River, and mark the words "New Jersey" on the south side, and the words "New York" on the north side, of every of the said monuments. (See R. S. of N. J., 1821, pp. 29-34.)

The above was confirmed by the king in council September 1, 1773.

In the year 1833 commissioners were appointed by New York and New Jersey for the settlement of the territorial limits and jurisdiction of the two States.

In the following year the commissioners made the following agreement, which was ratified by each State and confirmed by Congress, viz :

UNITED STATES STATUTES AT LARGE. TWENTY-THIRD CONGRESS, SESSION I. 1834.

AN ACT giving the consent of Congress to an agreement or compact entered into between the State of New York and the State of New Jersey, respecting the territorial limits and jurisdiction of said States.

ARTICLE FIRST. The boundary line between the two States of New York and New Jersey, from a point in the middle of Hudson River, opposite the point on the west shore thereof, in the forty-first degree of north latitude, as heretofore ascertained, and marked, to the main sea, shall be the middle of the said river, of the bay of New York, of the waters between Staten Island and New Jersey and of Raritan Bay, to the main sea; except as hereinafter otherwise particularly mentioned.

ARTICLE SECOND. The State of New York shall retain its present jurisdiction of and over Bedloe's and Ellis's Islands, and shall also retain exclusive jurisdiction of and over the other islands lying in the waters above mentioned and now under the jurisdiction of that State.

ARTICLE THIRD. The State of New York shall have and enjoy exclusive jurisdiction of and over all the waters of Hudson River lying west of Manhattan Island and to the south of the mouth of Spuytenduyvel Creek; and of and over the lands covered by the said waters to the low-water mark on the westerly or New Jersey side thereof; sub-

ject to the following rights of property and of jurisdiction of the State of New Jersey, that is to say:

1. The State of New Jersey shall have the exclusive right of property in and to the land under water lying west of the middle of the bar of New York, and west of the middle of that part of the Hudson River which lies between Manhattan Island and New Jersey.

2. The State of New Jersey shall have the exclusive jurisdiction of and over the wharves, docks, and improvements made and to be made on the shore of the said State; and of and over all vessels aground on said shore, or fastened to any such wharf or dock, except that the said vessels shall be subject to the quarantine or health laws, and laws in relation to passengers, of the State of New York, which now exist or which may hereafter be passed.

3. The State of New Jersey shall have the exclusive right of regulating the fisheries on the westerly side of the middle of said waters: *Provided*, That the navigation be not obstructed or hindered.

ARTICLE FOURTH. The State of New York shall have exclusive jurisdiction of and over the waters of the Kill Von Kull between Staten Island and New Jersey to the westernmost end off Shorter's Island in respect to such quarantine laws, and laws relating to passengers, as now exist or may hereafter be passed under the authority of that State, and for executing the same; and the said State shall also have exclusive jurisdiction, for the like purposes, of and over the waters of the sound from the westernmost end of Shorter's Island to Woodbridge Creek, as to all vessels bound to any port in the said State of New York.

ARTICLE FIFTH. The State of New Jersey shall have and enjoy exclusive jurisdiction of and over all the waters of the sound between Staten Island and New Jersey lying south of Woodbridge Creek, and of and over all the waters of Raritan Bay lying westward of a line drawn from the light-house at Prince's Bay to the mouth of Mat-tavan Creek; subject to the following rights of property and of jurisdiction of the State of New York, that is to say:

1. The State of New York shall have the exclusive right of property in and to the land under water lying between the middle of the said waters and Staten Island.

2. The State of New York shall have the exclusive jurisdiction of and over the wharves, docks, and improvements made and to be made on the shore of Staten Island, and of and over all vessels aground on said shore, or fastened to any such wharf or dock; except that the said vessels shall be subject to the quarantine of health laws, and laws in relation to passengers of the State of New Jersey which now exist or which may hereafter be passed.

3. The State of New York shall have the exclusive right of regulating the fisheries between the shore of Staten Island and the middle of said waters: *Provided*, That the navigation of the said waters be not obstructed or hindered.

In 1876 commissioners were appointed to re-locate the land boundary between New York and New Jersey, and replace monuments that may have become dilapidated or removed, or to erect new ones, etc. (*Vide* Rev. of N. J., 1877.)

The above commissioners found in some cases a slight discrepancy between the original marks and the verbal description thereof, and the legislatures of each State ordered that the original monuments should be considered the true boundary. (*See* acts of New York, 1880, and acts of New Jersey, 1881.)

In the year 1774 commissioners were appointed by New York and Pennsylvania to fix the beginning of the 43d degree of north latitude

on the Mohawk or western branch of Delaware River, which is the northeast corner of Pennsylvania, and to proceed westward and fix the line between Pennsylvania and New York.

These commissioners reported in December of the same year that they fixed the said northeast corner of Pennsylvania, and marked it as follows, viz :

On a small island in the said river they planted a stone marked with the letters and figures, New York, 1774, cut on the north side thereof; and the letters and figures, latitude 42° variation $4^{\circ} 20'$, cut on the top thereof; and in a direction due west from thence on the west side of the said branch of Delaware, collected and placed a heap of stones at the water mark; and proceeding further west four perches, planted another stone in the said line marked with the letters and figures, Pennsylvania, 1774, cut on the south side thereof, and the letters and figures, latitude 42° variation $4^{\circ} 20'$, cut on the top thereof, and at the distance of eighteen perches due west from the last-mentioned stone marked an ash tree. The rigor of the season prevented them running the line farther.

Nothing further seems to have been done until 1786-'7, when commissioners were appointed to finish the work thus begun (*see* Cary & Biorden's Laws of Pennsylvania, Vol. III, page 392), and the lines were run and monuments erected. The line was ratified in 1789, and is as follows, viz :

Beginning at a point in Lake Erie, where the boundary line between the United States and Great Britain is intersected by a meridian line drawn through the most westerly bent or inclination of Lake Ontario; then south along said meridian line to a monument in the beginning of the forty-third degree of north latitude, erected in the year one thousand seven hundred and eighty-seven, by Abraham Herdenbergh and William W. Morris, commissioners on the part of this State, and Andrew Ellicott and Andrew Porter, commissioners on the part of the State of Pennsylvania, for the purpose of marking the termination of the line of jurisdiction between this State and the said State of Pennsylvania; then east along the line established and marked by said last-mentioned commissioners to the ninetieth mile-stone in the same parallel of latitude, erected in the year one thousand seven hundred and eighty-six, by James Clinton and Simeon DeWitt, commissioners on the part of this State, and Andrew Ellicott, commissioner on the part of Pennsylvania; which said ninetieth mile-stone stands on the western side of the south branch of the Tioga River; then east along the line established and marked by said last-mentioned commissioners, to a stone erected in the year one thousand seven hundred and seventy-four, on a small island in the Delaware River, by Samuel Holland and David Rittenhouse, commissioners on the part of the colonies of Pennsylvania and New York, for the purpose of marking the beginning of the forty-third degree of north latitude; then down along said Delaware River to a point opposite to the fork or branch formed by the junction of the stream called Mahackamack with the said Delaware River, in the latitude of forty-one degrees, twenty-one minutes and thirty-seven seconds north; then in a straight line to the termination on the east bank of the Delaware River of a line run in the year one thousand seven hundred and seventy-four, by William Wickham and Samuel Gale, commissioners on the part of the then colony of New York, and John Stevens and Walter Rutherford, commissioners on the part of the then colony of New Jersey. (*See Revised Statutes of New York, 1881.*)

The meridian line forming the western boundary of New York was surveyed and mapped in 1790 by Andrew Ellicott, as United States commissioner (Pa. Archives, Vol. XII—Map), and the latitude formerly

inscribed on the monument on Lake Erie, fixing the western boundary, was $42^{\circ} 16' 13''$. The report of the commissioner has not been found.

In 1865 Dr. Peters, director of Hamilton College Observatory, under the directions of the Regents of the University of New York, determined the latitude and longitude of the boundary monument aforesaid, with the following result: Latitude, $42^{\circ} 16' 2''.8$; longitude, $79^{\circ} 45' 54''.4$. (*Vide* Dr. Peters' Report, 1868.)

In 1877 the parallel of the forty-second degree north latitude was ascertained at four points, by the New York and Pennsylvania Joint Boundary Commission, with the following result, viz:

1. At Travis Station (Hale's Eddy), very near the east end of that part of the New York and Pennsylvania line supposed to be on the forty second parallel, the old line was found to be 275 feet north of the parallel.

2. At Finn's Station, about 20 miles from east end (Great Bend), the line is 350 feet south of the parallel.

3. At Burt's Station, about 70 miles from east end (Wellsburg), the line is 760 feet north of the parallel.

4. At Clark's Station, about 253 miles from east end (Wattsburg), the line is 150 feet north of the parallel.

(See pamphlet, Report of Penn. Board of the Penn. & N. Y. Joint Boundary Comm.)

NEW JERSEY.

Although the original grants from the French and English sovereigns of 1603 and 1606 covered the territory forming the present State of New Jersey, the grant which first directly relates to New Jersey is that given in 1664 by the Duke of York to Lord John Berkeley and Sir George Carteret, two months before the setting out of his expedition to take possession of New York.

The following extract from that grant defines the boundaries, viz:

All that tract of land adjacent to New England, and lying and being to the westward of Long Island and Manhitas Island, and bounded on the east part by the main sea and part by Hudson's River, and hath upon the west Delaware Bay or river, and extendeth southward to the main ocean as far as Cape May, at the mouth of Delaware Bay, and to the northward as far as the northernmost branch of the said bay or river of Delaware, which is forty-one degrees and forty minutes of latitude, and crosseth over thence in a strait line to Hudson's River in forty-one degrees of latitude; which said tract of land is hereafter to be called by the name or names of New Cæsarea or New Jersey. (*Vide* Grants, Concessions, etc., of New Jersey, Leaming & Spicer, p. 8.)

In March, 1673, Lord Berkeley sold his undivided moiety of New Jersey to John Fenwick, by whom, in the following year, it was again sold. July 1, 1676, was executed the famous "Quintipartite deed," by which

the eastern part was given to Sir George Carteret, to be called East New Jersey, and the western part to the other proprietors, to be called West New Jersey. Sir George Carteret, at his death in 1678, left his land to be sold. It was sold in 1682 to the twelve proprietors, who admitted other partners.

Confirmation grants were made to the proprietors of both provinces by the Duke of York, and confirmed by the King, but between 1697 and 1701 the proprietors repeatedly made petitions to be allowed to surrender their right of government to the Crown. Accordingly, in 1702, the surrender was made and accepted by the Queen, and both parts united were made the province of New Jersey. (*Vide* Leaming and Spicer's grants, etc.)

(For the history of the northern and eastern boundary, *vide* New York, p. 73.)

The grant from the Duke of York to Berkeley and Carteret defined the west boundary of New Jersey to be the Delaware River. (*Vide* p. 76.)

The line between New Jersey and Delaware is thus described in the Revised Statutes of Delaware, p. 2, viz:

Low-water mark on the eastern side of the river Delaware, within the twelve-mile circle from New Castle and the middle of the bay, below said circle.

In 1876 the legislature of New Jersey authorized the governor to commence a suit in the Supreme Court of the United States to settle the boundary between New Jersey and Delaware. New Jersey claimed jurisdiction to the middle of the Delaware, so far as the river and bay is a boundary between the two States. (*Vide* Revision of New Jersey, p. 1185.)

In 1783 Commissioners were appointed by New Jersey and Pennsylvania to settle the jurisdiction of the river Delaware and the islands within the same. Their report was ratified, and is in substance as follows:

First. It is declared that the river Delaware from the station point or northwest corner of New Jersey, northerly to the place upon the said river where the circular boundary of the State of Delaware touches upon the same, in the whole length and breadth thereof, is and shall continue to be and remain a common highway, equally free and open for the use, benefit, and advantage of the said contracting parties, etc.

Second. That each State shall enjoy and exercise a concurrent jurisdiction within and upon the water, and not upon the dry land between the shores of said river, etc.

Third. That all islets, islands, and dry land within the bed and between the shores of said river, and between said station point northerly and the falls of Trenton southerly, shall, as to jurisdiction, be hereafter deemed and considered as parts and parcels of the State to which such insulated dry land doth lie nearest at the time of making this agree-

ment, and that from said falls of Trenton to the State of Delaware southerly, certain islands (in the agreement they are named B) be annexed to each State respectively. (*Vide* Revision of New Jersey, p. 1181.)

In 1786 commissioners were appointed by New Jersey and Pennsylvania for more accurately determining and describing the islands mentioned in the foregoing agreement; that is, those in the Delaware from the northwest corner of New Jersey down to the falls of Trenton. Their report was ratified, and a long list of islands, described by name in the act, were annexed to each State respectively. (*Vide* Revision of New Jersey, pp. 1182-83.)

PENNSYLVANIA.

The Swedish West India Company, chartered by the King of Sweden in 1625, established the first permanent settlement on the west bank of the Delaware, occupying a part of the territory now in Pennsylvania and Delaware, although the Dutch had previously established trading posts, which had been destroyed by the Indians. The Swedes acquired, by successive purchases from the Indian chiefs, all the land extending from Cape Henlopen to the great falls of the Delaware, calling it New Sweden. (*Vide* C. and C., p. 1509.)

In 1655 this territory was surrendered to the Dutch. (*Vide* Hazard's Annals of Pennsylvania, p. 185.)

By the conquest of the New Netherlands, in 1664, the Duke of York seems to have successfully claimed the settlements on the west bank of the Delaware as a part of his dominions.

In 1681 Charles II of England granted to William Penn the Province of Pennsylvania. The following extract from the charter defines the boundaries:

* * * all that Tracte or Parte of Land in America, with all the Islands therein conteyned, as the same is bounded on the East by Delaware River, from twelve miles distance Northwards of New Castle Towne unto the three and fortieth degree of Northern Latitude, if the said River doeth extende so farre northwards; But if the said River shall not extend soe farre Northward, then by the said River soe farr as it doth extend; and from the head of the said River the Eastern Bounds are to bee determined by a Meridian Line, to bee drawne from the head of the said River, unto the said three and fortieth degree. The said Lands to extend westwards five degrees in longitude, to bee computed from the said Easterne Bounds; and the said Lands to bee bounded on the North by the beginning of the three and fortieth degree of Northern Latitude, and on the South by a Circle drawne at twelve miles distance from New Castle Northward and Westward unto the beginning of the fortieth degree of Northern Latitude, and thence by a streight Line Westward to the Limit of Longitude above mentioned.

William Penn, in order to perfect his title, procured of the Duke of York a deed bearing date August 21, 1682, by which the Duke of York conveyed to him all title and claim which he might have to the province of Pennsylvania. (*Vide* Hazard's Annals of Pa., 586 *et seq.*)

He also purchased of the Duke of York the territory now comprising the State of Delaware, which he held until 1701-'2, when he granted a charter which enabled them to set up a separate government, though still under proprietary control. (*Vide* C. and C., p. 270 *et seq.*)

(For a history of the northern and eastern boundaries of Pennsylvania, see New York and New Jersey, pp. 71 and 76.)

That part of the southern boundary of Pennsylvania between Pennsylvania and Delaware is an arc of a circle, having for its center the steeple of the old court-house at New Castle, Del., and a radius of 12 miles. This was surveyed and marked under a warrant from William Penn in 1701. (*Vide* Hazard's Annals of Pennsylvania.)

This circular line, in connection with adjacent lines, was made the subject of controversy for many years.

According to the original grants of Pennsylvania and Maryland the boundary between them was to be the fortieth degree of north latitude.

This line being found to pass north of Philadelphia and to exclude Pennsylvania from Delaware Bay, negotiations ensued between the proprietors to rectify this geographical blunder, and for nearly a century the matter remained unsettled.

In the year 1732 an agreement was made to fix the boundary. Commissioners were appointed in that year, and subsequently in 1739, to run the line, but they failed to agree, and chancery suits were the result. Taking a decision of Lord Chancellor Hardwick in 1750 as a basis of final adjudication, an agreement was signed July 4, 1760. By this agreement the line between Pennsylvania and Delaware on the one part and Maryland on the other was determined as follows, viz:

A due east and west line should be run across the peninsula from Cape Henlopen to the Chesapeake Bay. From the exact middle of this line should be drawn a line tangent to the western periphery of a circle, having a radius of 12 English statute miles, measured horizontally from the center of the town of New Castle. From the tangent point a line should be drawn due north until it cut a parallel of latitude 15 miles due south of the most southern part of the city of Philadelphia, this point of intersection to be the northeast corner of Maryland; thence the line should run due west on said parallel as far as it formed a boundary between the two governments. (*Vide* Delaware, p. 81.)

In 1760 commissioners and surveyors were appointed, who spent three years in measuring the base line and the tangent line between Maryland and Delaware.

The proprietors then, wearied with the delay, sent over from England two famous mathematicians, Charles Dixon and Jeremiah Mason, who verified the work of their predecessors, and ran the line west between Pennsylvania and Maryland, since known as "Mason and Dixon's line."

Mason and Dixon fixed the latitude of this line at $39^{\circ} 43' 18''$. A resurvey in 1850 by Colonel Graham determined it to be $39^{\circ} 43' 26''.3$.

Mason and Dixon begun their work in 1763, and were stopped by Indians in 1767, having run the line about 244 miles west of the Delaware, not quite finishing their work. They put up mile stones all along said line, every fifth one being marked with the arms of the respective proprietors.

In consequence of the accidental removal of the stone at the north-east corner of Maryland, commissioners were appointed in 1850 by Pennsylvania, Delaware, and Maryland to revise the former survey, which was done by Lieutenant-Colonel Graham, of the United States topographical engineers. The result confirmed the work of Mason and Dixon, and Maryland gained by the resurvey a little less than two acres.

(For a full report of the running of Mason and Dixon's line in 1763-'67, and the verification by Colonel Graham in 1850, see Senate Journal of Delaware for 1851, pages 56-109.)

In 1784 the report of the commissioners who had been appointed to fix the boundaries between Virginia and Pennsylvania (West Virginia then forming part of Virginia) was confirmed, and the lines so fixed are as follows, viz:

The line commonly called Mason and Dixon's line to be extended due west five degrees of longitude from the river Delaware, for the southern boundary of Pennsylvania, and a meridian drawn from the western extremity thereof to the northern limits of the said States, respectively, be the western boundary of Pennsylvania. (*Vide* C. and B. laws of Pennsylvania, Vol. II, p. 495, and Hening's Virginia, Vol. XI, p. 554.)

By the cession of 1784, by Virginia to the United States—and that of 1800, by Connecticut to the United States, and the formation of the State of West Virginia from a portion of Virginia in 1862—the above-mentioned meridian line becomes the boundary between Pennsylvania on the east, and Ohio and West Virginia on the west.

By an examination of the cession of 1781, by New York to the United States, it will be seen that a small triangular tract on Lake Erie was left in the hands of the General Government. This was sold to Pennsylvania in 1792.

DELAWARE.

The State of Delaware was originally settled by the Swedes. (*Vide* Pennsylvania, p. 78.) In 1655 it was surrendered to the Dutch, who, in 1664, in turn surrendered it to the English, and it was taken possession of by the Duke of York.

William Penn, having received in 1682 a grant of the province of Pennsylvania, bought of the Duke of York the territory comprising the present State of Delaware. It was conveyed to him by two deeds

of feoffment, dated August 24, 1682, one conveying the town of New Castle and a twelve-mile circle around the same, and the other conveying all the lands south of said circle to Cape Henlopen. (See Hazard's Annals of Pennsylvania, p. 588, *et seq.*)

Soon after the grant made by the royal charter aforesaid, an assembly of the province and three lower counties (then called the territories) was called by the proprietary and governor aforesaid, which met at Chester on the seventh day of December, 1682, when the following laws, among others, were passed, to wit:

“ . . . Since . . . it has pleased King Charles the Second . . . to grant . . . William Penn, esq., . . . this Province of Pennsylvania . . .
And . . . James Duke of York and Albany . . . to release his right and claim . . . to the Province of Pennsylvania . . . and . . . to grant unto the said William Penn . . . all that tract of land from twelve miles northward of New Castle, on the river Delaware, down to the South Cape (commonly called Cape Henlopen, and by the Proprietary and Governor now called Cape Jomus) lying on the west side of the said river and bay, . . . lately cast into three counties, called New Castle, Jones, and Whorekills (alias New Dale. . . . Be it enacted . . . that the counties of New Castle, Jones, and Whorekills alias New Dale . . . are annexed to the Province of Pennsylvania. . . . (Dallas' Laws of Pennsylvania, 1797, Vol. I, Appendix, p. 24, *et seq.*)

In 1701 William Penn granted a charter, under which the province of Pennsylvania and the territories (as Delaware was then called) were made separate governments, though both were still under the proprietary government of William Penn. (C. & C., p. 270.)

By the Revolution the “territories” became the State of Delaware, with substantially her present boundaries.

(For a history of the boundaries between Delaware and Pennsylvania, *vide* Pennsylvania, p. 79, and between Delaware and New Jersey, *vide* New Jersey, p. 77, *et seq.*)

From 1732 to 1769 there was a controversy between the proprietors of Pennsylvania and Maryland in regard to boundaries (*vide* p. 79). The boundaries of Delaware on the north and west—Delaware then being under the jurisdiction of Pennsylvania—were determined as follows, viz:

Beginning at Cape Henlopen and running due west 34 miles 309 perches; thence in a straight line 81 miles 78 chains and 30 links up the peninsula until it touches and makes a tangent to the western periphery of a circle, drawn at the horizontal distance of twelve English statute miles from the center of the town of New Castle.

From this tangent point a line was run due north till it cut a parallel of latitude 15 miles due south of the most southern part of the city of Philadelphia. This point of intersection is the northeast corner of Maryland. The tangent line bearing a little west of north, the due north line from the tangent point cuts off an arc of the 12-mile circle. The boundary line follows the arc of the circle from the tangent point around to the point where the due north line intersects the 12-mile

circle, then follows said due north line to said northeast corner of Maryland. The length of said due north line is 5 miles 1 chain and 50 links, as given by Mason and Dixon. (*Vide Jour. Del. Sen.*, 1851, p. 56 *et seq.*)

By the agreement of 1760, based on the decree of Chancellor Hardwick, a due east and west line should be run across the peninsula from Cape Henlopen to Chesapeake Bay, etc. The decree of Lord Hardwick says, touching the position of Cape Henlopen, "that Cape Henlopen ought to be deemed and taken to be situated at the place where the same is laid down and described in the map or plan annexed to the said articles to be situated, and therefore his lordship doth further order and decree that the said articles be carried into execution accordingly," etc.

In Hazard's *Annals of Pennsylvania*, p. 5, is found the following, viz: "The cape now called Henlopen was then called Cornelis."

William Penn directed that Cape Henlopen be called Cape James. (*Vide Hazard's Pennsylvania*, p. 606; also *vide* Act of union of the territories to Pennsylvania.)

The foregoing statements explain the seeming incongruity between the base line across the peninsula and the position of Cape Henlopen as laid down on all modern maps.

MARYLAND.

The territory comprising the present area of Maryland was included in the previous charters of Virginia, notwithstanding which, in the year 1632, Lord Baltimore received a royal grant of the province of Maryland, whose boundaries are defined in the following extract:

All that part of the Peninsula or Chersonese, lying in parts of America, between the ocean on the east and the Bay of Chesapeake on the west; divided from the residue thereof by a right line drawn from the promontory or headland called Watkins Point, situate upon the bay aforesaid, near the River Wighoo on the west unto the main ocean on the east, and between that boundary on the south unto that part of the Bay of Delaware on the north, which lieth under the fortieth degree of north latitude from the equinoctial, where New England is terminated; and all the tract of that land within the metes underwritten (that is to say), passing from the said bay, called Delaware Bay, in a right line, by the degree aforesaid, unto the true meridian of the first fountain of the River Pattowmack; thence verging towards the south unto the farther bank of the said river, and following the same on the west and south unto a certain place called Cinquack, situate near the mouth of said river, where it disembogues into the aforesaid Bay of Chesapeake, and thence by the shortest line unto the aforesaid promontory or place called Watkins Point, so that the whole tract of land divided by the line aforesaid, between the main ocean and Watkins Point unto the promontory called Cape Charles, may entirely remain forever excepted to us * * * * *

By an examination of the limits laid down in this charter, and a comparison with the several charters of Virginia and the charter and deeds

to William Penn, it will be seen that there was a conflict of boundaries on both sides of the Maryland grant.

The history of the long controversy with Pennsylvania has already been given (*vide* Pennsylvania, p. 79, and Delaware, p. 80). Virginia on the south claimed the territory under her charters, and for a time seemed disposed to assert her claim, notwithstanding we find in 1638 a proclamation by the governor and council of Virginia recognizing the province of Maryland, and forbidding trade with the Indians within the limits of Maryland without the consent of Lord Baltimore previously obtained (*vide* Bozman's Maryland, vol. II, p. 586). Virginia's claim was finally given up by a treaty or agreement made in 1658. (For a full account *vide* Bozman's Maryland, p. 444 *et seq.*)

In 1663 the Virginia assembly ordered a survey of the line between Virginia and Maryland on the peninsula, and declared it to be as follows, viz:

From Watkins Point east across the peninsula.

They define Watkins Point

To be the north side of Wicomicoe River on the Eastern shore and neere unto and on the south side of the streight limbe opposite to Patuxent River.

(*Vide* Hening's Virginia, vol. II, p. 184.)

In 1668 commissioners were appointed by Maryland and Virginia to fix the boundary across the peninsula. The commissioners were Philip Calvert, esq., chancellor of Maryland, and Col. Edmund Scarbrugh, his majesty's surveyor-general of Virginia. Their report is as follows, viz:

* * * After a full and perfect view taken of the point of land made by the north side of Pocomoke Bay and south side of Annemessex Bay have and do conclude the same to be Watkins Point, from which said point so called, we have run an east line, agreeable with the extreamest part of the westernmost angle of the said Watkins Point, over Pocomoke River to the land near Robert Holston's, and there have marked certain trees which are so continued by an east line running over Swansecutes Creeke into the marsh of the seaside with apparent marks and boundaries * * * Signed June 25, 1668. (*Vide* Md. Hist. Soc. Coll. of State papers, volume marked 4 L. C. B., pp. 63-64.)

Virginia, by the adoption of her constitution of 1776 (see Article 21), relinquished all claim to territory covered by the charter of Maryland, thereby fixing Maryland's western boundary as follows:

Commencing on a true meridian of the first fountain of the river Pattawmack, thence verging towards the south unto the further bank of the said river and following the same on the west and south unto a certain place called Cinquack, situate near the mouth of said river where it disembogues into the aforesaid bay of Chesapeake, and thence by the shortest line unto the aforesaid promontory or place called Watkins Point, thence a right line to the main ocean on the east. (See charter of Maryland.)

The foregoing are substantially the present boundaries; but from that time up to the present a controversy has been going on concerning them.

In 1786 a compact was entered into between the States of Maryland and Virginia, but as this referred more particularly to the navigation

and exercise of jurisdiction on the waters of Chesapeake Bay, the Potomac and Pocomoke Rivers, they are not given here. (*Vide* Hening's Va., Vol. XII, p. 50.)

From 1821 to 1858 frequent legislation took place in regard to this boundary.

In the last-named year commissioners were appointed by Maryland and Virginia, respectively, who, with the assistance of Lieut. N. Michler, United States Engineers, surveyed the lines.

In 1860 the governor of Virginia, under a resolution of the legislature, appointed and sent an agent to England to collect records and documentary evidence bearing on this question.

The rebellion ensuing, nothing further was done until 1867, when legislation again commenced.

The question of this boundary was referred to arbitrators by an agreement made in 1874, each State binding itself to accept their award as final and conclusive.

J. S. Black, of Pennsylvania; William A. Graham, of North Carolina, and Charles A. Jenkins, of Georgia, were appointed arbitrators.

William A. Graham having died, James B. Beck, of Kentucky, was appointed in his stead.

The arbitrators made, in 1877, the following award, viz:

Beginning at the point on the Potomac River where the line between Virginia and West Virginia strikes the said river at low-water mark, and thence following the meanderings of said river by the low-water mark to Smith's Point, at or near the mouth of the Potomac, in the latitude $37^{\circ} 53' 8''$ and longitude $76^{\circ} 13' 46''$; thence crossing the waters of the Chesapeake Bay, by a line running north $65^{\circ} 30'$ east, about nine and a half nautical miles to a point on the western shore of Smith's Island at the north end of Sassafras Hammock, in latitude $37^{\circ} 57' 13''$, longitude $76^{\circ} 2' 52''$; thence across Smith's Island south $88^{\circ} 30'$ east five thousand six hundred and twenty yards to the center of Horse Hammock, on the eastern shore of Smith's Island, in latitude $37^{\circ} 57' 8''$, longitude $75^{\circ} 59' 20''$; thence south $79^{\circ} 30'$ east four thousand eight hundred and eighty yards to a point marked "A" on the accompanying map, in the middle of Tangier Sound, in latitude $37^{\circ} 56' 42''$, longitude $75^{\circ} 56' 23''$, said point bearing from James Island light south 54° west, and distant from that light three thousand five hundred and sixty yards; thence south $10^{\circ} 30'$ west four thousand seven hundred and forty yards by a line dividing the waters of Tangier Sound, to a point where it intersects the straight line from Smith's Point to Watkins Point, said point of intersection being in latitude $37^{\circ} 54' 21''$, longitude $75^{\circ} 56' 55''$, bearing from James Island light south 29° west and from Horse Hammock south $34^{\circ} 30'$ east. This point of intersection is marked "B" on the accompanying map. Thence north $85^{\circ} 15'$ east six thousand seven hundred and twenty yards along the line above mentioned, which runs from Smith's Point to Watkins Point until it reaches the latter spot, namely Watkins Point, which is in latitude $37^{\circ} 54' 38''$, longitude $75^{\circ} 52' 44''$. From Watkins Point the boundary line runs due east seven thousand eight hundred and eighty yards to a point where it meets a line running through the middle of Pocomoke Sound, which is marked "C" on the accompanying map, and is in latitude $37^{\circ} 54' 38''$, longitude $75^{\circ} 47' 50''$; thence by a line dividing the waters of Pocomoke Sound north $47^{\circ} 30'$ east five thousand two hundred and twenty yards to a point in said sound marked "D" on the accompanying map, in latitude $37^{\circ} 56' 25''$, longitude $75^{\circ} 45' 26''$; thence following the middle

of Pocomoke River by a line of irregular curves, as laid down on the accompanying map, until it intersects the westward protraction of the boundary line marked by Scarborough and Calvert, May 28, 1668, at a point in the middle of Pocomoke River, and in the latitude $37^{\circ} 59' 37''$, longitude $75^{\circ} 37' 4''$; thence by the Scarborough and Calvert line, which runs $5^{\circ} 15'$ north of east, to the Atlantic Ocean.

The latitudes, longitudes, courses, and distances here given have been measured upon the Coast Chart No. 33 of U. S. Coast Survey, sheet No. 3, Chesapeake Bay. * * * The middle thread of the Pocomoke River and the low-water mark on the Potomac River are to be measured from headland to headland, without considering or following arms, inlets, creeks, bays, or affluent rivers. * * * (*Vide* U. S. Stat. at Large, Vol. XX, p. 481.)

This award was ratified by the States of Maryland and Virginia, and confirmed by Congress in 1879.

In 1879-'80 acts were passed by the legislatures of Maryland and Virginia to appoint commissioners and to request the General Government to designate one or more officers of the Engineer Corps, said commissioners and officers to survey and mark said line and erect monuments thereon.

West Virginia having been formed from a part of Virginia and admitted into the Union in 1862, the western boundary of Maryland now separates it from the State of West Virginia.

The commissioners appointed in 1859 by Virginia and Maryland (*vide* p. 84) surveyed the western boundary from the "Fairfax Stone" (the first fountain of the Potomac) due north to the Pennsylvania line, and the legislature of Maryland in 1860 passed an act declaring that line to be its western boundary.

From the "Fairfax Stone" the boundary between Maryland and West Virginia runs along the south bank of the Potomac River till it strikes the line between Virginia and West Virginia.

(For a history of the placing of the Fairfax Stone, *vide* Virginia, p. 90.)

DISTRICT OF COLUMBIA.

On the 5th day of September, 1774, the Continental Congress met at Philadelphia. Two years later they adjourned to Baltimore. During the Revolution and subsequent to the treaty of peace they met in various places. After the close of the war much debate took place in regard to the location of a permanent seat of the Government of the United States. Several States made propositions to Congress, offering to cede certain lands for the purpose, but no determination of the location was made by Congress until 1790.

Act of cession from the State of Maryland, passed December 23, 1788.

On the 23d of December, 1788, the State of Maryland passed the following act, viz :

Be it enacted by the general assembly of Maryland, That the representatives of this
(541)

State in the House of Representatives of the Congress of the United States, appointed to assemble at New York, on the first Wednesday of March next, be and they are hereby authorized and required on the behalf of this State to cede to the Congress of the United States, any district in this State not exceeding ten miles square, which the Congress may fix upon and accept for the seat of government of the United States.

In the following year (December 3, 1789), the State of Virginia passed a similar act, of which the following is an extract :

Be it therefore enacted by the general assembly, That a tract of country not exceeding ten miles square or any lesser quantity, to be located within the limits of the State, and in any part thereof as Congress may by law direct shall be, and the same is hereby, forever ceded and relinquished to the Congress and Government of the United States, in full and absolute right and exclusive jurisdiction, as well of said soil as of persons residing or to reside thereon, pursuant to the tenor and effect of the eighth section of the 1st article of the Constitution of the Government of the United States.

After long discussion, Congress in 1790, in view of the foregoing cessions of Maryland and Virginia, passed the following act, viz :

AN ACT for establishing the temporary and permanent seat of government of the United States.
Approved July 16, 1790.

SECT. 1. *Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,* That a district of territory, not exceeding ten miles square, to be located as hereafter directed on the river Potowmac, at some place between the mouth of the Eastern Branch and Connoyocheque, be, and the same is hereby, accepted for the permanent seat of the government of the United States. *Provided nevertheless,* That the operation of the laws of the State within such district shall not be affected by this acceptance until the time fixed for the removal of the government thereto, and until Congress shall otherwise by law provide.

SECT. 2. *And be it further enacted,* That the President of the United States be authorized to appoint, and by supplying vacancies happening from refusals to act or other causes, to keep in appointment as long as may be necessary, three commissioners, who, or any two of whom, shall, under the direction of the President, survey, and by proper metes and bounds define and limit, a district of territory, under the limitations above mentioned ; and the district so defined, limited, and located shall be deemed the district accepted by this act for the permanent seat of the government of the United States.

SECT. 3. *And be it enacted,* That the said commissioners, or any two of them, shall have power to purchase or accept such quantity of land on the eastern side of the said river within the said district as the President shall deem proper for the use of the United States, and according to such plans as the President shall approve. The said commissioners, or any two of them, shall, prior to the first Monday in December in the year 1800, provide suitable buildings for the accommodation of Congress, and of the President, and for the public offices of the government of the United States.

SECT. 4. *And be it enacted,* That for defraying the expenses of such purchases and buildings the President of the United States be authorized and requested to accept grants of money.

SECT. 5. *And be it enacted,* That prior to the first Monday in December next all offices attached to the seat of government of the United States shall be removed to, and until the first Monday in December in the year 1800 shall remain at, the city of Philadelphia, in the State of Pennsylvania, at which place the session of Congress next ensuing the present shall be held.

SECT. 6. *And be it enacted,* That on the first Monday in December, in the year 1800, the seat of the government of the United States, shall, by virtue of this act, be transferred to the district and place aforesaid. And all offices attached to the said seat of government shall accordingly be removed thereto by their respective holders, and

shall, after the said day, cease to be exercised elsewhere, and that the necessary expense of said removal, shall be defrayed out of the duties on imposts and tonnage, of which a sufficient sum is hereby appropriated.

In the following year the foregoing act was amended, in order to include a portion of the Eastern Branch, and the town of Alexandria within the limits of the district.

The following is the act of amendment:

AN ACT to amend "An act for establishing the temporary and permanent seat of government of the United States." Approved March 3, 1791.

Be it enacted, &c., That so much of the act entitled "An act for establishing the temporary and permanent seat of the government of the United States, as requires that the whole of the district of territory, not exceeding ten miles square, to be located on the river Potowmac, for the permanent seat of the government of the United States, shall be located above the mouth of the Eastern Branch, be and is hereby repealed, and that it shall be lawful, for the President to make any part of the territory below said limit and above the mouth of Hunting Creek, a part of the said district so as to include a convenient port of the Eastern Branch, and of the lands lying on the lower side thereof; and also the town of Alexandria, and the territory so to be included shall form a part of the district not exceeding ten miles square for the permanent seat of the government of the United States, in like manner, and to all intents and purposes, as if the same had been within the the purview of the above recited act: *Provided*, That nothing herein contained, shall authorize the erection of the public buildings, otherwise than on the Maryland side of the river Potowmac, as required by the aforesaid act.

In pursuance of the foregoing acts, three commissioners were appointed, who made preliminary surveys of the territory, and on the 30th day of March, 1791, George Washington, President of the United States, issued a proclamation, in which the bounds of the said District were defined as follows, viz:

Beginning at Jones' Point, being the upper cape of Hunting Creek, in Virginia, and at an angle in the outset of 45° west of the north, and running in a direct line ten miles for the first line; then beginning again at the same Jones' Point and running another direct line at a right angle with the first, across the Potomac, ten miles for the second line; then, from the terminations of the said first and second lines, running two other direct lines, of ten miles each, the one crossing the Potomac and the other the Eastern Branch aforesaid, and meeting each other in a point.

In 1800 Congress removed to this District. In the following year the District was divided into two counties, as follows, viz:

UNITED STATES STATUTES AT LARGE, SIXTH CONGRESS, SECOND SESSION, 1801,
(CHAPTER XV).

AN ACT concerning the District of Columbia.

The said District of Columbia shall be formed into two counties. One county shall contain all that part of said District which lies on the east side of the river Potomac, together with the islands therein, and shall be called the county of Washington, the other county shall contain all that part of said District which lies on the west side of said river, and shall be called the county of Alexandria; and the said river, in its whole course through said District, shall be taken and deemed to all intents and purposes to be within both of said counties.

In 1846 Congress passed an act retroceding to the State of Virginia that part of the District of Columbia originally ceded to the United States by Virginia. The following is an extract from said act of retrocession :

That with assent of the people of the county and town of Alexandria, to be ascertained as hereinafter prescribed, all of that portion of the District of Columbia ceded to the United States by the State of Virginia, and all the rights and jurisdiction therewith ceded over the same, be, and the same are, hereby ceded and forever relinquished to the State of Virginia in full and absolute right and jurisdiction, as well of soil as of persons residing or to reside thereon.

VIRGINIA.

In the year 1606 King James I of England granted the "First Charter of Virginia." The boundaries therein described are as follows, viz:

* * * Situate, lying, or being all along the sea coasts, between four and thirty degrees of northerly latitude from the equinoctial line, and five and forty degrees of the same latitude, and in the main land between the same four and thirty and five and forty degrees and the islands thereunto adjacent, or within one hundred miles of the coast thereof. * * *

Soon after, in 1609, a new charter was granted, called the "Second Charter of Virginia," which defines the boundaries in the following terms:

* * * Situate, lying, and being in that part of America called Virginia, from the point of land called Cape or Point Comfort, all along the sea coast to the northward two hundred miles, and from the said point of Cape Comfort all along the sea coast to the southward two hundred miles, and all that space and circuit of land lying from the sea coast of the precinct aforesaid up into the land, throughout from sea to sea, west and northwest, and also all the islands lying within one hundred miles along the coast of both seas of the precinct aforesaid. * * *

In 1611-'12 the "Third Charter of Virginia" was granted, which was an enlargement of the second, of which the following is an extract:

All and singular those islands whatsoever, situate and being in any part of the ocean seas bordering upon the coast of our said first colony in Virginia, and being within three hundred leagues of any of the portes heretofore granted to the said treasurer and company in our former letters-patents as aforesaid, and being within or between the one-and-fortieth and thirtieth degrees of northerly latitude.

These boundaries, as will be seen, included territory composing wholly, or in part, the present States of Pennsylvania, Delaware, Maryland, North and South Carolina, in addition to others formed since the Revolution.

This large extent of territory was reduced in the first instance by the charter of Maryland in 1632, next by the charters of Carolina in 1663 and 1665, then by the charter of Pennsylvania in 1681, and, again, subsequent to the Revolution, by the cession to the United States of the territory northwest of the Ohio River in 1784; by the admission of

Kentucky as an independent State in 1792, and lastly by the division of the territory of Virginia in 1862, by which the new State of West Virginia was created and admitted into the Union.

By the constitution of 1776 Virginia formally gave up all claim to the territory now appertaining to the neighboring States of Maryland, Pennsylvania, North and South Carolina.

The following is an extract from the Virginia constitution of 1776:

The territories contained within the charters erecting the colonies of Maryland, Pennsylvania, North and South Carolina, are hereby ceded, released, and forever confirmed to the people of these colonies, respectively, with all the rights of property, jurisdiction, and government, and all the rights whatsoever, which might at any time heretofore have been claimed by Virginia, except the free navigation and use of the rivers Potomaque and Pokomoke, with the property of the Virginia shores and strands bordering on either of said rivers, and all improvements which have been or shall be made thereon. The western and northern extent of Virginia shall, in all other respects, stand as fixed by the charter of King James I, in the year one thousand six hundred and nine, and by the public treaty of peace between the courts of Britain and France in the year one thousand seven hundred and sixty-three, unless by act of the legislature one or more governments be established westwards of the Alleghany Mountains.

In the mean time a grant of territory had been made, within the present limits of Virginia and West Virginia, which caused great dissatisfaction to the people of the Virginia Colony, and which ultimately had an important bearing in settling the divisional line between Maryland and Virginia.

In the 21st year of Charles II a grant was made to Lord Hapton and others of what is called the northern neck of Virginia, which was sold by the other patentees to Lord Culpeper and confirmed to him by letters-patent in the fourth year of James II. This grant carried with it nothing but the right of soil and incidents of ownership, it being expressly subjected to the jurisdiction of the government of Virginia. The tract of land thereby granted was "bounded by and within the heads of the rivers Tappahannock, alias Rappahannock, and Quirough, alias Patomac, rivers." On the death of Lord Culpeper, this proprietary tract descended to Lord Fairfax, who had married Lord Culpeper's only daughter.

As early as 1729 difficulties sprung up, arising from conflicting grants from Lord Fairfax and the Crown.

In 1730 Virginia petitioned the King, reciting that the head springs of the Rappahannock and Potomac Rivers were not known, and praying that such measures might be taken that they might be ascertained to the satisfaction of all parties.

In 1733 Lord Fairfax made a similar petition, asking that a commission might issue for running out, marking, and ascertaining the true boundaries of his grant.

An order, accordingly, was issued and three commissioners were appointed on the part of the Crown and three on the part of Lord Fairfax.

The duty which devolved upon these commissioners was to ascertain by actual examination and survey the respective fountains of the Rappahannock and Potomac Rivers. This survey was made in 1736.

The report of the commissioners was referred to the council for plantation affairs in 1738, who reported their decision in 1745, as follows, viz:

* * * The said boundary ought to begin at the first spring of the south branch of the river Rappahannock, and that the said boundary be from thence drawn in a straight line northwest to the place in the Alleghany Mountains where that part of the Potomac River, which is now called Cohongoroota, first rises. * * *

This report was confirmed by the King, and commissioners were appointed to run and mark the dividing line accordingly.

The line was run in 1746. On the 17th day of October, 1746, they planted the Fairfax stone at the spot which had been described and marked by the preceding commissioners as the true head spring of the Potomac River, and which, notwithstanding much controversy, has continued to be regarded, from that period to the present time, as the southern point of the western boundary between Virginia and Maryland. (*Vide* Faulkner's Report to Governor of Virginia, 1832. For full details, *vide* Byrd Papers, 1866, Vol. II, p. 83 *et seq.* Also Hening's Va. Statutes.)

This tract of country was held by Lord Fairfax and his descendants many years, but subsequent to the Revolution the quitrents, charges, etc., were abolished and it became in all respects subject to the jurisdiction of Virginia.

(For the history of the settlement of the boundary lines between Virginia and Maryland, *vide* Maryland, p. 83.)

(For a history of the boundary between Virginia and Pennsylvania, *vide* Pennsylvania, p. 80.)

Kentucky formed originally a part of the county of Fincastle, Virginia. In the year 1776, this county was divided into three counties, the westernmost of which was called Kentucky County, and its eastern boundary was declared to be as follows, viz:

A line beginning on the Ohio, at the mouth of Great Sandy Creek, and running up the same and the main or northeasterly branch thereof to the Great Laurel Ridge or Cumberland Mountains; thence southwesterly along the said mountain to the line of North Carolina. (See Hening's Statutes, Virginia, Vol. 9, p. 257.)

Kentucky having been admitted into the Union June 1, 1792, commissioners were appointed in 1798 by Virginia and Kentucky to fix the boundary. In 1799-1800 the commissioners' report was made and ratified by the States. It was as follows, viz:

To begin at the point where the Carolina, now Tennessee, line crosses the top of the Cumberland Mountains, near Cumberland Gap, thence northeastwardly along the top or highest part of the said Cumberland Mountain, keeping between the head waters of Cumberland and Kentucky Rivers, on the west side thereof, and the head waters of Powell's and Guest's Rivers, and the Pound Fork of Sandy, on the east side thereof, continuing along the said top, or highest part of said mountain, crossing the road

leading over the same at the Little Paint Gap, where by some it is called the Hollow Mountain and where it terminates at the West Fork of Sandy, commonly called Russell's Fork, thence with a line to be run north 45° east till it intersects the other great principal branch of Sandy, commonly called the Northeastwardly branch, thence down the said Northeastwardly branch to its junction with the main west branch and down Main Sandy to its confluence with the Ohio. (See Shepard's Virginia, Vol. 2, p. 234.)

It will be seen that the latter part of this line is the present line between West Virginia and Kentucky.

(For the history of the settlement of the boundaries between Virginia and North Carolina, *vide* North Carolina, *vide* p. 94.)

In 1779 Virginia and North Carolina appointed commissioners to run the boundary line between the two States west of the Alleghany Mountains, on the parallel of $36^{\circ} 30'$. The commissioners were unable to agree on the location of the parallel; they therefore ran two parallel lines two miles apart, the northern known as Henderson's, and claimed by North Carolina, the southern known as Walker's line, and claimed by Virginia. In the year 1789 North Carolina ceded to the United States all territory west of her present boundaries, and Tennessee being formed from said ceded territory, this question became one between Virginia and Tennessee.

Commissioners having been appointed by Virginia and Tennessee to establish the boundary, their report was adopted in 1803, and was as follows, viz:

A due west line equally distant from both Walker's and Henderson's, beginning on the summit of the mountain generally known as White Top Mountain, where the northeast corner of Tennessee terminates, to the top of the Cumberland Mountain, where the southwestern corner of Virginia terminates.

In 1871 Virginia passed an act to appoint commissioners to adjust this line.

Tennessee, the following year, in a very emphatic manner, passed a resolution refusing to reopen a question regarding a boundary which she considered "fixed and established beyond dispute forever." (See acts of Tennessee, 1872.)

Up to 1783 Virginia exercised jurisdiction over a large tract of country northwest of the Ohio River. But by a deed executed March 1, 1784, she ceded to the United States all territory lying northwest of the Ohio River, thus making her western boundary the west bank of the Ohio River.

On the 31st of December, 1862, the State of Virginia was divided, and 48 counties, composing the western part of the State, were made the new State of West Virginia. By an act of Congress in 1866, consent was given to the transfer of two additional counties from Virginia to West Virginia.

In 1873 and 1877 commissioners were appointed by each State to determine the true boundaries between the two States, and the General

Government was asked to detail officers of engineers to act with said commissioners in surveying and fixing the line.

Until their report is at hand, the boundary can only be found by following the old county lines. In view of the expectation of such report at an early day, it has not been thought best to go into an examination of the old county lines.

WEST VIRGINIA.

This State was set off from Virginia on December 31, 1862. It was originally formed of those counties of Virginia which had refused to join in the secession movement. It was admitted to the Union as a separate State, June 19, 1863. It originally contained the following counties: Barbour, Boone, Braxton, Brooke, Cabell, Calhoun, Clay, Doddridge, Fayette, Gilmer, Greenbrier, Hampshire, Hancock, Hardy, Harrison, Jackson, Kanawha, Lewis, Logan, Marion, Marshall, Mason, McDowell, Mercer, Monongalia, Monroe, Morgan, Nicholas, Ohio, Pendleton, Pleasants, Pocahontas, Preston, Putnam, Raleigh, Randolph, Ritchie, Roane, Taylor, Tucker, Tyler, Upshur, Wayne, Webster, Wetzell, Wirt, Wood, Wyoming.

In 1866 it was enlarged by the two counties of Berkeley and Jefferson, transferred from Virginia. Its boundary with Virginia is made up of boundary lines of the border counties above enumerated; and can be defined only by reference to the laws by which these counties were created. In the constitution of 1872, after a recapitulation of the counties which were transferred from Virginia to West Virginia, is found the following clause defining the boundaries upon the south and west:

The State of West Virginia includes the bed, bank, and shores of the Ohio River, and so much of the Big Sandy River as was formerly included in the Commonwealth of Virginia, and all territorial rights and property in and jurisdiction over the same heretofore reserved by and vested in the Commonwealth of Virginia, are vested in and shall hereafter be exercised by the State of West Virginia; and such parts of the said beds, banks, and shores as lie opposite and adjoining the several counties of this State shall form parts of said several counties respectively.

(For a history of the boundaries of West Virginia, *vide* Pennsylvania, p. 79; Maryland, p. 83; Virginia, p. 88.)

NORTH CAROLINA.

In the year 1663 the "first charter of Carolina" was granted, which, two years later, in 1665, was enlarged by the "second charter of Carolina."

The following extracts from these two charters define the boundaries :

Charter of Carolina, 1663.

* * * All that territory or tract of ground, scituate, lying and being within our dominions of America, extending from the north end of the island called Lucke Island, which lieth in the Southern Virginia seas, and within six and thirty degrees of the northern latitude, and to the west as far as the south seas, and so southerly as far as the river Saint Matthias, which bordereth on the coast of Florida, and within one and thirty degrees of northern latitude, and so west in a direct line as far as the south seas aforesaid. * * *

Charter of Carolina, 1665.

* * * All that province, territory, or tract of land, scituate, lying or being in our dominions of America, aforesaid, extending north and eastward as far as the north end of Currituck River, or inlet, upon a strait westerly line to Wyonoke Creek, which lies within or about the degrees of thirty-six and thirty minutes, northern latitude, and so west in a direct line as far as the south seas. * * *

This is an extension of the charter of 1663, by which its northern boundary was removed from the approximate latitude of 36° to $36^{\circ} 30'$, on which parallel it is now approximately established. Although the exact year in which the division of the province of Carolina into the two provinces of North and South Carolina appears somewhat uncertain, I find it generally put down as 1729. The division line between the two provinces, North and South Carolina, appears to have been established by mutual agreement.

In the constitution of North Carolina of 1776 this line is defined as shown in the subjoined extract :

The property of the soil, in a free government, being one of the essential rights of the collective body of the people, it is necessary, in order to avoid future disputes, that the limits of the State should be ascertained with precision ; and as the former temporary line between North and South Carolina was confirmed and extended by commissioners appointed by the legislatures of the two States, agreeable to the order of the late King George II in council, that line, and that only, should be esteemed the southern boundary of this State ; that is to say, beginning on the sea side at a cedar stake, at or near the mouth of Little River (being the southern extremity of Brunswick County), and running from thence a northwest course through the boundary house, which stands in thirty-three degrees fifty-six minutes, to thirty-five degrees north latitude, and from thence a west course so far as is mentioned in the charter of King Charles II to the late proprietors of Carolina. Therefore, all the territory, seas, waters, and harbours, with their appurtenances, lying between the line above described, and the southern line of the State of Virginia, which begins on the sea shore, in thirty-six degrees thirty minutes north latitude, and from thence runs west, agreeable to the said charter of King Charles, are the right and property of the people of the State, to be held by them in sovereignty, any partial line, without the consent of the legislature of this State, at any time thereafter directed or laid out in anywise notwithstanding.

On December 2, 1789, the legislature passed an act ceding to the United States its western lands, now constituting the State of Tennessee. On February 25, 1790, the deed was offered, and on April 2 of the same year it was accepted by the United States.

In the Revised Statutes the north and south boundaries of the State are claimed to be as follows: The northern boundary, the parallel of $36^{\circ} 30'$; the southern boundary, a line running northwest from Goat Island on the coast in latitude $33^{\circ} 56'$ to the parallel of 35° , and thence along that parallel to Tennessee; while the western boundary is the Smoky Mountains. It is strange that the Revised Statutes should contain such a statement of the boundary lines when it is thoroughly well known that it is incorrect, especially as regards the southern boundary. In the case of the northern boundary the intention has been from the earliest colonial times down to the present to establish a line upon the parallel of $36^{\circ} 30'$. This is found to be the wording of every legislative act relating to it, and the errors of this boundary are due simply to errors in surveying and location. The following brief and comprehensive sketch of the north and south boundary lines of this State, and of the various attempts made to locate them, is taken from Professor Kerr's "Geology of North Carolina," vol. I, page 2:

"The first and only serious attempt to ascertain the northern boundary was that made in 1728, by Col. Wm. Byrd, and others, commissioners on the part of the two colonies, acting under Royal authority. From the account given by Byrd of this undertaking, it appears that they started from a point on the coast whose position they determined by observation to be in $36^{\circ} 31'$ north latitude, and ran due west (correcting for the variation of the compass), to Nottoway River, where they made an offset of a half mile to the mouth of that stream, again running west. The line was run and marked 242 miles from the coast, to a point in Stokes County, on the upper waters of the Dan River (on Peter's creek) the North Carolina commissioners accompanying the party only about two-thirds of the distance. Beyond this point, the line was carried some 90 miles by another joint commission of the two colonies in 1749; this survey, terminating at Steep Rock Creek, on the east of Stone Mountain, and near the present northwest corner of the State, was estimated to be 329 miles from the coast. In 1779 the line was taken up again at a point on Steep Rock Creek, determined by observation to be on the parallel of $36^{\circ} 30'$ (the marks of the previous survey having disappeared entirely), and carried west to and beyond Bristol, Tennessee. This last is known as the Walker line, from one of the commissioners of Virginia.

These lines were run and the latitude observations taken with very imperfect instruments, and the variation of the compass was little understood, so that it was not possible to trace a parallel of latitude. The line, besides, was only marked on the trees and soon disappeared, and as the settlements were very scattered the location soon became a matter of vague tradition and presently of contention and litigation, so that in 1858, at the instance of Virginia, commissioners were appointed to relocate the line from the end of the Byrd survey westward, but for some reason they did not act. In 1870 commissioners were again appointed by Virginia and similar action asked on the part of this State; and the proposition was renewed in 1871, but ineffectually, as before. In all these numerous attempts to establish the line of division between the two colonies and States, the intention and the specific instructions have been to ascertain and mark, as the boundary of the two States, *the parallel of $36^{\circ} 30'$* . The maps published towards the end of last century by Jefferson and others give that parallel as the line, and the bill of rights of North Carolina claims that "all the territory lying between the line above described (the line between North and South Carolina) and the southern line of the State of Virginia, which begins on the sea shore in $36^{\circ} 30'$ north latitude, and from thence runs west, agreeably to the

charter of King Charles, are the right and property of this State." But it appears from the operations of the United States Coast Survey at both ends of the line that the point of beginning on Currituck Inlet, instead of being, as so constantly assumed, in latitude $36^{\circ} 30'$, or as determined by the surveyors in 1728, $36^{\circ} 31'$ is $36^{\circ} 33' 15''$, and the western end (of "the Walker line," of 1779, at Bristol, Tenn.) $36^{\circ} 34' 25.5''$. It is stated in Byrd's Journal that the variation of the compass was ascertained to be a little less than 3° W. [The magnetic chart of the United States Coast Survey would make it 3° E.] And no account is given of any subsequent correction, and if none was made at the end of the line surveyed by him the course would have been in error by nearly 3° , as the amount of variation in this State changes a little more than 1° for every 100 miles of easting or westing. So that the northern boundary of the State as run is not only not the parallel of $36^{\circ} 30'$, but is far from coincident with any parallel of latitude, and must be a succession of curves, with their concavities northward and connected at their ends by north and south offsets.

The southern boundary between this State and South Carolina and Georgia was first established by a joint colonial commission in 1735 to 1746. The commissioners run a line from Goat Island on the coast (in latitude $33^{\circ} 56'$ as supposed) NW to the parallel of 35° , according to their observations, and then due west to within a few miles of the Catawba River, and here, at the old Salisbury and Charleston road, turned north along that road to the southeast corner of the Catawba Indian Lands. This line, resurveyed in 1764, was afterwards (in 1772) continued along the eastern and northern boundaries of the Catawba lands to the point where the latter intersects the Catawba River; thence along and up that river to the mouth of the South Fork of the Catawba, and thence due west, as supposed, to a point near the Blue Ridge. This part of the line was resurveyed and confirmed by commissioners under acts of assembly of 1803, 1804, 1806, 1813, 1814, and 1815, and continued west to and along the Saluda Mountains and the Blue Ridge to the intersection of the "Cherokee boundary" of 1797, and thence in a direct line to the Chatooga River at its intersection with the parallel of 35° . From this point the line was run west to the Tennessee line, between this State and Georgia, in 1807, and confirmed and established by act of 1819.

The boundary between this State and Tennessee was run, according to the course designated in the act of 1789, entitled "An act for the purpose of ceding to the United States certain western lands therein described" (the State of Tennessee); that is, along the crest of the Smoky Mountains, from the Virginia line to the Cataluche River (in Haywood County), in 1799, under act of 1796. It was continued from this point to the Georgia line in 1821. The commissioners who completed this line, at the date last-mentioned, instead of following their instructions, diverged from the crest of the Smoky (Unaka) Mountains at the intersection of the Hiwassee turnpike, and run due south to the Georgia line, thereby losing for the State the valuable mining region since known as Ducktown.

And as to the southern boundary, the point of beginning on Goat Island is in latitude $33^{\circ} 51' 37''$, as shown by the Coast Survey, and instead of running from Goat Island northwest to latitude of 35° and thence along that parallel, it appears, from the South Carolina Geographical State Survey of 1821-'25, that the course from the starting point is N. $47^{\circ} 30'$ W., and instead of pursuing the parallel of 35° it turns west about 10 miles south of that line, and then on approaching the Catawba River, turns northward pursuing a zigzag line to the forks of the Catawba River, which is about 12 miles north of that parallel; and from this point to the mountains the boundary line (of 1772) runs, not west, but N. 88° W., bringing its western end about 17 miles too far north, and reaching the (supposed) parallel of 35° at a distance of about 130 miles east of the Catawba River. The loss of territory resulting from these singular deviations is probably between 500 and 1,000 square miles.

The following extract from the constitution of 1796, of Tennessee,

(551)

defines the eastern boundary of that State, which is the western boundary of North Carolina, as it was intended to be run and marked :

Beginning on the extreme height of the Stone Mountain at the place where the line of Virginia intersects it in latitude thirty-six degrees and thirty minutes north ; running thence along the extreme height of the said mountain to the place where Watanga River breaks through it ; thence a direct course to the top of the Yellow Mountain, where Bright's road crosses the same ; thence along the ridge of said mountain between the waters of Doe River and the waters of Rock Creek, to the place where the road crosses the Iron Mountain ; from thence along the extreme height of said mountain to where Nolichucky River runs through the same ; thence to the top of the Bald Mountain ; thence along the extreme height of said mountain to the Painted Rock on French Broad River ; thence along the highest ridge of said mountain to the place where it is called the Great Iron or Smoky Mountain ; thence along the extreme height of said mountain to the place where it is called Unicoi or Unaka Mountain between the Indian towns of Cowee and Old Chota ; thence along the main ridge of the said mountain to the southern boundary of this State as described in the act of cession of North Carolina to the United States of America.

In 1879 the legislature passed an act to appoint commissioners to make a survey from the northeast corner of Georgia westward. This point of commencement is common to North Carolina, South Carolina, and Georgia.

In 1881 the legislature passed another act, providing for the appointment of a commissioner, who should act with commissioners from Virginia, South Carolina, Georgia, or Tennessee, to re-run and re-mark the boundaries between North Carolina and the other States.

SOUTH CAROLINA.

The territory included in the present State of South Carolina was included in the charter of Carolina, which also embraced what is now the State of Georgia. (*Vide* North Carolina, p. 93.)

In 1729 the province of Carolina was divided, forming the two provinces of North Carolina and South Carolina. In 1732 the extent of South Carolina was reduced by the charter of Georgia. (*Vide* Georgia, p. 97.)

(For a history of the settlement of the boundary between North Carolina and South Carolina, *vide* North Carolina, p. 93.)

By the charter of Georgia the line between South Carolina and Georgia was to be the Savannah River, to the head thereof. In 1762 difficulties having arisen, concerning the interpretation of the charter, as regarded the head of the Savannah, and also the title to the lands south of the Altamaha River, Georgia made complaint to the King, who issued a proclamation in 1763 giving the lands between the Altamaha and Saint Mary's Rivers to Georgia. The question of the boundary on the Savannah, however, remained unsettled until 1787, when a conven-

tion between the two States was held at Beaufort, S. C., to determine the same, and the line was fixed as at present.

The following is an extract from the articles of agreement:

The most northern branch or stream of the river Savannah from the sea or mouth of such stream to the fork or confluence of the rivers now called Tugaloo and Keowa, and from thence the most northern branch or stream of the said river Tugaloo till it intersects the northern boundary line of South Carolina, if the said branch or stream of Tugaloo extends so far north, reserving all the islands in the said rivers Savannah and Tugaloo to Georgia; but if the head spring or source of any branch or stream of the said river Tugaloo does not extend to the north boundary line of South Carolina, then a west line to the Mississippi, to be drawn from the head spring or source of the said branch or stream of Tugaloo River which extends to the highest northern latitude, shall forever hereafter form the separation, limit, and boundary between the States of South Carolina and Georgia. (Laws of the United States, Vol. I, p. 466.)

In the same year South Carolina ceded to the United States a narrow strip of territory south of the North Carolina line, which she claimed, about 12 or 14 miles wide, and extending to the Mississippi River; this strip now forms the northern portion of Georgia, Alabama, and Mississippi. Georgia being thus increased in extent northwardly, the line between the two States is clearly expressed in the code of South Carolina, as follows, viz:

The Savannah River, from its entrance into the ocean to the confluence of the Tugaloo and Keowa Rivers; thence by the Tugaloo River to the confluence of the Tugaloo and Chatooga Rivers; thence by the Chatooga River to the North Carolina line in the thirty-fifth degree of north latitude, the line being low-water mark at the southern shore of the most northern stream of said rivers, where the middle of the rivers is broken by islands, and middle thread of the stream where the rivers flow in one stream or volume.

GEORGIA.

Georgia was included in the proprietary charter granted to the lords proprietors of Carolina in 1663 and 1665, for which a provincial charter was substituted in 1719.

In 1732 the charter of Georgia as an independent colony was granted by King George II, of which the following is an extract:

All those lands, countrys, and territories situate, lying and being in that part of South Carolina, in America, which lies from the most northern part of a stream or river there, commonly called the Savannah, all along the sea-coast to the southward, unto the most southern stream of a certain other great water or river called the Altamaha, and westerly from the heads of the said rivers, respectively, in direct lines to the south seas.

This charter was surrendered in 1752 and a provincial government established. (O. & C., p. 369 *et seq.*)

In 1763 the territory between the Altamaha and Saint Mary's Rivers was added to Georgia by royal proclamation. (*Vide* South Carolina, p. 96.)

In the constitution adopted by Georgia in 1798 the boundaries are declared. The following is an extract therefrom :

The limits, boundaries, jurisdictions, and authority of the State of Georgia do, and did, and of right ought to extend from the sea or mouth of the river Savannah along the northern branch or stream thereof, to the fork or confluence of the rivers now called Tugalo and Keowee, and from thence along the most northern branch or stream of the said river Tugalo, till it intersect the northern boundary line of South Carolina, if the said branch or stream of Tugalo extends so far north, reserving all the islands in the said rivers Savannah and Tugalo to Georgia; but if the head, spring, or source of any branch or stream of the said river Tugalo does not extend to the north boundary line of South Carolina, then a west line to the Mississippi, to be drawn from the head, spring, or source of the said branch or stream of Tugalo River, which extends to the highest northern latitude; thence down the middle of the said river Mississippi, until it shall intersect the northernmost part of the thirty-first degree of north latitude, south by a line drawn due east from the termination of the line last mentioned, in the latitude of thirty-one degrees north of the equator, to the middle of the river Apalachicola or Chatahoochee; thence along the middle thereof, to its junction with Flint River; thence straight to the head of Saint Mary's River, and thence, along the middle of Saint Mary's River, to the Atlantic Ocean, and from thence to the mouth or inlet of Savannah River, the place of beginning, including and comprehending all the lands and waters within the said limits, boundaries, and jurisdictional rights; and also all the islands within twenty leagues of the sea-coast.

In 1802 Georgia entered into articles of agreement and cession with the United States, whereby Georgia ceded to the United States the lands west of her present boundaries, and the United States ceded to Georgia that part of the South Carolina cession of 1787 which lies east of the present western boundary of Georgia. The following extracts show the limits of the two cessions :

The State of Georgia cedes to the United States all the right, title, and claim which the said State has to the jurisdiction and soil of the lands situated within the boundaries of the United States, south of the State of Tennessee and west of a line beginning on the western bank of the Chatahouchee River where the same crosses the boundary line between the United States and Spain; running thence up the said river Chatahouchee, and along the western bank thereof to the great bend thereof, next above the place where a certain creek or river, called "Upchee" (being the first considerable stream on the western side, above the Cussetas and Coweta towns), empties into the said Chatahouchee River; thence in a direct line to Nickajack, on the Tennessee River; thence crossing the said last-mentioned river, and thence running up the said Tennessee River and along the western bank thereof to the southern boundary line of the State of Tennessee.

The United States * * * cede to the State of Georgia * * * the lands * * * situated south of the southern boundaries of the States of Tennessee, North Carolina, and South Carolina, and east of the boundary line herein above described as the eastern boundary of the territory ceded by Georgia to the United States.

For a history of the boundary between Georgia and South Carolina, *vide* South Carolina, p. 96.

The history of the boundary between North Carolina and Georgia has already been given (*vide* North Carolina, p. 95). It may be proper, however, to add that this line (the thirty-fifth degree of north latitude) was fixed by the cession above detailed, from the United States to Georgia

of that part of the South Carolina cession east of the present western boundary of Georgia.

A long controversy ensued between Georgia and North Carolina, with no results, however, until in 1810 Georgia empowered her governor to employ Mr. Andrew Ellicott to ascertain the true location of the thirty-fifth degree of latitude. Ellicott did so, and the point fixed by him was acquiesced in. (*Vide Cobb's Georgia Digest*, p. 150.)

The boundary between Georgia and Tennessee was established in 1818, and is as follows, viz: The thirty-fifth parallel of north latitude, beginning and ending as follows:

Beginning at a point in the true parallel of the thirty-fifth degree of north latitude, as found by James Cormack, mathematician on the part of the State of Georgia, and James S. Gaines, mathematician on the part of the State of Tennessee, on a rock about two feet high, four inches thick, and fifteen inches broad, engraved on the north side thus: "June 1st, 1818; var. 6½ east," and on the south side thus: "Geo. 35 North; J. Cormack," which rock stands one mile and twenty-eight poles from the south bank of the Tennessee River, due south from near the center of the old Indian town of Nickajack, and near the top of the Nickajack Mountain, at the supposed corner of the State of Georgia and Alabama; thence running due east, leaving old D. Ross two miles and eighteen yards in the State of Tennessee, and leaving the house of John Ross about two hundred yards in the State of Georgia, and the house of David McNair one mile and one-fourth of a mile in the State of Tennessee, with blazed and mile-marked trees, lessening the variation of the compass by degrees, closing it at the termination of the line on the top of the Unicoi Mountain at five and one-half degrees. (*Vide C. Stat. of Tenn.*, pp. 243-244.)

The boundary between Georgia and Florida was fixed by the treaty of 1783, between the United States and Great Britain, substantially as at present, viz: Commencing in the middle of the Apalachicola or Catahouche River, on the thirty-first degree of north latitude; thence along the middle thereof to its junction with the Flint River; thence straight to the head of Saint Mary's River, and thence down along the middle of Saint Mary's River to the Atlantic ocean (*vide Treaty of 1783*). This boundary was affirmed by the treaty of 1795 between the United States and Spain, and commissioners were appointed to run the entire line between the United States and the Spanish territory. (*Vide Treaty of 1795*.)

In 1819 Spain ceded the Floridas to the United States. In 1822 Florida was made a Territory and in 1825 was admitted into the Union as an independent State.

In 1826 Congress took action as indicated below:

UNITED STATES STATUTES AT LARGE, NINETEENTH CONGRESS, SESSION I, 1826.

AN ACT to authorize the President of the United States to run and mark a line dividing the Territory of Florida from the State of Georgia.

The line shall be run straight from the junction of said rivers Chatahoochie and Flint, to the point designated as the head of Saint Mary's River.

This boundary line was long unsettled, a controversy arising concerning the true point to be considered to be the head of the Saint Mary's

River, as Georgia contended that the point fixed upon by the Spanish and American commissioners under the treaty of 1795 was incorrect.

In 1859 commissioners were appointed by Georgia and Florida to rerun the line. Florida ratified their report in 1861, and Georgia in 1866.

The detailed report of the commissioners is not at hand, but the line is declared in the statutes of Georgia as follows, viz :

From a point on the western bank of the Chattahoochee River in the 31st degree of north latitude; thence along the line or limit of high-water mark to its junction with the Flint River; thence along a certain line of survey made by Gustavus J. Orr, a surveyor on the part of Georgia, and W. Whitner, a surveyor on the part of Florida, beginning at a four-and-aft tree, about four chains below the present junction; thence along this line east, to a point designated thirty-seven links north of Ellicott's Mound on the St. Mary's River; thence along the middle of said river to the Atlantic Ocean. (*Vide* Code of Ga., 1873, p. 7.)

This line is also given in the code of Florida, and differs in one respect, viz, from the thirty-first degree of north latitude down the middle of said river to its confluence with the Flint River, etc. (*Vide* Code of Florida, 1872.)

The line between Georgia and Alabama was fixed by the act of cession of Georgia to the United States in 1802.

In 1822-'25, Georgia desiring to have the line run from the Chattahoochee to where it strikes the Tennessee line, appointed commissioners for that purpose, and requested the co-operation of Alabama and the United States, both, however, failing to take action. The Georgia commissioners ran the line from Nickajack, on the Tennessee line, to Miller's Bend, on the Chattahoochee. (For a history of the controversy concerning this line, *vide* laws of Georgia, 1822-'24-'25-'26.)

Alabama protested against the above line and made repeated efforts to reopen negotiations concerning it, to all which Georgia sturdily refused to accede, until finally, January 24, 1840, the legislature of Alabama passed the following joint resolution, viz :

Resolved, That the State of Alabama will, and do, hereby accept, as the true dividing line between this State and that of Georgia, the line which was run and marked out by the commissioners of Georgia in 1826, beginning at what is called Miller's Bend, on the Chattahoochee River; thence along said marked line to Nickajack.

The line is given in the code of Alabama in the following words, viz :

The boundary line between Alabama and Georgia commences on the west side of the Chattahoochee River at the point where it enters the State of Florida; from thence up the river, along the western bank thereof, to the point on Miller's Bend next above the place where the Uchee Creek empties into such river; thence in a direct line to Nickajack. (See code of Alabama, 1876, p. 189.)

In James's Hand-book of Georgia, 1876, p. 121, is the following description of the western boundary of Georgia, viz :

From Nickajack the line between Georgia and Alabama runs south 9° 30' east to Miller's Bend, on the Chattahoochee River, about 146 miles; thence down the western bank of the river at high-water mark to its junction with Flint River, at a point now four chains below the actual junction, latitude 30° 42' 42", longitude 80° 53' 15".

FLORIDA.

Florida was originally settled by the Spaniards, and was held as a Spanish province nearly two hundred years. In 1762 it was ceded by Spain to Great Britain, who divided it into the two provinces of East and West Florida, separated by the Appalachian River, with a northern boundary substantially as at present. (*Vide* Fairbanks' History of Florida.)

In 1783 Great Britain retroceded Florida to Spain, and the northern boundary was fixed by the treaty of peace between the United States and Great Britain signed in the same year. Spain, however, claimed the territory as far north as the parallel of latitude of the mouth of the Yazoo River.

Previous to this, in 1763, France had ceded Louisiana to Spain, which Spain retroceded to France in 1800, and in 1803 France ceded the same to the United States, who claimed that the eastern boundary of the said province of Louisiana, so often ceded, was the Perdido River, while Spain claimed it to be the Iberville River and Lakes Maurepas and Pontchartrain. The controversy arising from the difference of interpretation of these various treaties and cessions was terminated by the treaty of Washington in 1819, whereby Spain ceded to the United States the provinces of East and West Florida.

On March 30, 1822, by an act of Congress, the territory ceded to the United States by Spain was made the "Territory of Florida," embracing the same extent as does the present State.

On March 3, 1845, Florida was admitted into the Union as an independent State.

(For a history of the northern boundary of Florida *vide* Georgia, p. 99.)

In 1831 Congress passed an act relating to the boundary between Florida and Alabama, of which the following is an extract:

AN ACT to ascertain and mark the line between the State of Alabama and the Territory of Florida, and the northern boundary of the State of Illinois, and for other purposes.

That the President of the United States be, and he is hereby, authorized to cause to be run and marked the boundary line between the State of Alabama and the Territory of Florida, by the surveyors-general of Alabama and Florida, on the thirty-first degree of north latitude.

(*Vide* U. S. Stat. at Large, Vol. IV, p. 479.)

In 1847 the agreement of commissioners previously appointed by Florida and Alabama was ratified, and the line is described as follows, viz:

Commencing on the Chattahoochee River near a place known as "Irwin's Mills" and running west to the Perdido, marked throughout by blazes on the trees, and also by mounds of earth thrown up on the line at distances of one mile, more or less, from each other, and commonly known as "Ellicott's Line," or the "Mound Line." (*Vide* Florida Code, 1873, p. 100.)

The line between the two States is given in general terms in the Florida Code as follows, viz:

Commencing at the mouth of the Perdido River, from thence up the middle of said river to where it intersects the south boundary line of the State of Alabama and the thirty-first degree of north latitude; then due east to the Chattahoochee River.

ALABAMA.

In 1798 the United States formed the Territory of Mississippi, including—

All that tract of country bounded on the west by the Mississippi, on the north by a line to be drawn due east from the mouth of the Yascous to the Chattahoochee River, on the east by the Chattahoochee River, and on the south by the thirty-first degree of north latitude. (*Vide* U. S. Stat. at Large, Vol. I, p. 549.)

In this act was a clause reserving the right of Georgia and of individuals to the jurisdiction of the soil thereof.

South Carolina and Georgia having ceded to the United States their claim to territory west of their present limits, the General Government, in 1804, by an act of Congress, annexed the tract of country lying north of Mississippi Territory and south of the State of Tennessee, and bounded on the east by Georgia and west by Louisiana, to the Territory of Mississippi. (*Vide* U. S. Stat. at Large, Vol. II, p. 305.) Also in 1812 the United States added to Mississippi Territory all the lands lying east of Pearl River, west of the Perdido and south of the thirty-first degree of latitude. (*Vide* U. S. Stat. at Large, Vol. II, p. 734.)

By these additions the Territory of Mississippi was made to comprise what is now included in the two States of Alabama and Mississippi. On March 8, 1817, by an act of Congress the Territory of Alabama was formed from the eastern portion of the Territory of Mississippi, with the following boundaries, viz:

Beginning at the point where the line of the thirty-first degree of north latitude intersects the Perdido River; thence east to the western boundary line of the State of Georgia; thence along said line to the southern boundary line of the State of Tennessee; thence west along said boundary line to the Tennessee River; thence up the same to the mouth of Bear Creek; thence by a direct line to the northwest corner of Washington County; thence due south to the Gulf of Mexico; thence, eastwardly, including all the islands within 6 leagues of the shore, to the Perdido River; and thence up the same to the beginning. (*Vide* U. S. Stat. at Large, Vol. III, p. 371.)

On December 14, 1819, Alabama was admitted as an independent State, with the above boundaries. It was, however, made the duty of the surveyor of the public lands south of Tennessee and the surveyor of lands in Alabama Territory to run and cut out the line of demarcation between the two States of Alabama and Mississippi, and if it should appear to said surveyors that so much of the line designated as

running due south from the northwest corner of Washington County to the Gulf of Mexico should encroach on the counties of Wayne, Greene, and Jackson, in the State of Mississippi, then the same should be altered so as to run in a direct line from the northwest corner of Washington County to a point on the Gulf of Mexico 10 miles east of the mouth of the River Pascagoula. (*Vide* U. S. Stat. at Large, Vol. III, p. 490.)

(For the history of the boundaries between Alabama and Georgia *vide* Georgia, p. 98. For the history of the boundaries between Alabama and Florida, *vide* Florida, p. 101.)

The boundary between Alabama and Tennessee is the thirty-fifth parallel of north latitude (*vide* North Carolina, p. 94); from Nickajack (*vide* Georgia, p. 98) west across the Tennessee River, and on to the second intersection of said river by said parallel. (*Vide* Alabama Code, 1876, p. 189.)

The boundary between Alabama and Mississippi was to be run by surveyors, under the act of admission of Alabama. The report of said surveyors is not at hand, but the line as laid down in the Mississippi Code is as follows, viz:

Beginning at a point on the west bank of the Tennessee River, six four-pole chains south of, and above, the mouth of Yellow Creek; thence up the said river to the mouth of Bear Creek; thence by a direct line to what was formerly the northwest corner of Washington County, Alabama; thence in a direct line to a point ten miles east of the Pascagoula River, on the Gulf of Mexico. (*Vide* Mississippi Code, pp. 48, 49.)

MISSISSIPPI.

(For the early history of the extent of Mississippi Territory *vide* Alabama, p. 102.)

On December 10, 1817, the western part of the Mississippi Territory was made a State and admitted into the Union, with the following boundaries, viz:

Beginning on the river Mississippi at the point where the southern boundary of the State of Tennessee strikes the same; thence east along the said boundary line to the Tennessee River; thence up the same to the mouth of Bear Creek; thence by a direct line to the northwest corner of the county of Washington; thence due south to the Gulf of Mexico; thence westwardly, including all the islands within six leagues of the shore, to the most eastern junction of Pearl River with Lake Borgne; thence up said river to the thirty-first degree of north latitude; thence west along said degree of latitude to the Mississippi River; thence up the same to the beginning. (*Vide* U. S. Stat. at Large, Vol. III, p. 348.)

(For further information concerning eastern boundary, *vide* Alabama, p. 102.)

In 1819 the line between Mississippi and Tennessee was run by commissioners. Their report is not at hand. In 1833 the legislature of

Tennessee passed an act establishing "Thompson's line." The details of "Thompson's line" have not been found. In 1837 the line was again run by commissioners from the two States, and ratified by the legislatures. The commissioners' report was as follows, viz:

Commencing at a point on the west bank of the Tennessee River six four-pole chains south, or above the mouth of Yellow Creek, and about three-quarters of a mile north of the line known as "Thompson's line," and twenty-six chains and ten links north of Thompson's line at the basis meridian of the Chickasaw surveys, and terminating at a point on the east bank of the Mississippi River (opposite Cow Island) sixteen chains north of Thompson's line. (See Laws of Tennessee, 1837, p. 27.)

The boundaries were fixed by the act of Congress admitting the State of Mississippi, as follows, viz:

Commencing at the most eastern junction of Pearl River with Lake Borgne, thence up said Pearl River to the thirty-first degree of north latitude, thence west along said degree of latitude to the Mississippi River, thence up the same to the point where the southern boundary of Tennessee strikes the same. (See U. S. Laws, vol. 6, p. 175.)

Mississippi claims to the middle of the Mississippi River, where the river forms her western boundary. (See Rev. Stat., 1857.)

LOUISIANA.

The original territory of Louisiana was acquired from France (see p. 19). In 1804, a portion of this, comprising the area of the present State of Louisiana, with the exception of the southeastern portion immediately adjoining the present State of Florida, was organized into a territory under the name of Orleans, while the balance of the Louisiana purchase retained the name of Louisiana Territory. On April 30, 1812, the Territory of Orleans was admitted as a State under the name of Louisiana, and at the same time the name of the Territory of Louisiana was changed to Missouri Territory. In the same year the limits of the State were enlarged in the southeast to its present boundaries.

The following act defines the Territory of Orleans:

All that portion of country ceded by France to the United States, under the name of Louisiana, which lies south of the Mississippi territory, and of an east and west line to commence on the Mississippi River at the thirty-third degree of north latitude, and to extend west to the western boundary of the said cession, shall constitute a Territory of the United States, under the name of the Territory of Orleans. (Eighth Congress, first session.)

The following clause from the act admitting Louisiana defines its original boundaries:

Beginning at the mouth of the river Sabine, thence by a line to be drawn along the middle of said river, including all islands, to the thirty-second degree of latitude; thence due north to the northernmost part of the thirty-third degree of north latitude; thence along the said parallel of latitude to the river Mississippi; thence down

the said river to the river Iberville; and from thence along the middle of the said river and lakes Maurepas and Pontchartrain to the Gulf of Mexico; thence, bounded by the said Gulf, to the place of beginning, including all islands within three leagues of the coast. (Twelfth Congress, first session.)

The following is a description of the addition to the State of Louisiana, in terms of the act:

Beginning at the junction of the Iberville with the river Mississippi, thence along the middle of the Iberville, the river Amite, and of the lakes Maurepas and Pontchartrain, to the eastern mouth of the Pearl River; thence up the eastern branch of Pearl River to the thirty-first degree of north latitude; thence along the said degree of latitude to the river Mississippi; thence down the said river to the place of beginning, shall become and form a part of the State of Louisiana. (Twelfth Congress, first session.)

TEXAS.

Texas declared its independence of Mexico in 1835. On December 29, 1845, it was admitted to the Union. As originally constituted, it embraced besides its present area the region east of the Rio Grande, now in New Mexico, extending north to the Arkansas River, its eastern limits coinciding with the western limit of the United States, as laid down in the treaty with Spain of 1819.

In 1848, the eastern boundary of the State was extended slightly, as noted in the following act:

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Congress consents that the legislature of the State of Texas may extend her eastern boundary so as to include within her limits one-half of Sabine Pass, one-half of Sabine Lake, also one-half of Sabine River, from its mouth as far north as the thirty-second degree of north latitude.

In 1850, the State sold to the General Government, for the sum of \$10,000,000, that part lying north of the parallel of $36^{\circ} 30'$, and that portion lying west of longitude 103° , as far south as the parallel of 32° , as set forth in the following clause from the act of Congress relating to this transfer:

First. The State of Texas will agree that her boundary on the north shall commence at the point at which the meridian of one hundred degrees west from Greenwich is intersected by the parallel of thirty-six degrees thirty minutes north latitude, and shall run from said point due west to the meridian of one hundred and three degrees west from Greenwich; thence her boundary shall run due south to the thirty-second degree of north latitude; thence on the said parallel of thirty-two degrees of north latitude to the Rio Bravo del Norte, and thence with the channel of said river to the Gulf of Mexico. (Thirty-first Congress, first session.)

The following act defines the northern boundary of Texas:

AN ACT to authorize the President of the United States, in conjunction with the State of Texas, to run and mark the boundary lines between the Territories of the United States and the State of Texas.

Beginning at the point where the one hundredth degree of longitude west from Greenwich crosses Red River, and running thence north to the point where said one

hundredth degree of longitude intersects the parallel of thirty-six degrees thirty minutes north latitude, and thence west with the said parallel of thirty-six degrees and thirty minutes north latitude to the point where it intersects the one hundred and third degree of longitude west from Greenwich; and thence south with the said one hundred and third degree of longitude to the thirty-second parallel of north latitude; and thence west with said thirty-second degree of north latitude to the Rio Grande. (Thirty-fifth Cong., first session.)

The boundary line of Texas is as follows:

Beginning in the Gulf of Mexico, at the outlet of Sabine Lake, the line passes northward through the middle of Sabine Lake and up the middle of Sabine River to the point where said river intersects the parallel of thirty-two degrees; thence north along the meridian of that point of intersection to the point where said meridian intersects Red River; thence up Red River to the one hundredth meridian west of Greenwich; thence north on said meridian to the parallel of thirty-six degrees thirty minutes; west on said parallel to the meridian of one hundred and three degrees west of Greenwich; thence south on said meridian to the parallel of latitude of 32°; thence west on that parallel to its point of intersection with the Rio Grande; thence down the mid-channel of the Rio Grande to its mouth.

ARKANSAS

The Territory of Arkansas, or Arkansaw, as it was originally spelled, was formed on March 2, 1819, from a part of Missouri Territory. The following clause from the act establishing it defines its limits in part:

All that part of the Territory of Missouri which lies south of a line beginning on the Mississippi River at thirty-six degrees north latitude, running thence west to the River St. François, thence up the same to 36° 30' north latitude, and thence west to the western territorial boundary line, shall, for the purposes of a Territorial government, constitute a separate Territory and be called the Arkansaw Territory.

In 1824 an act was passed by Congress fixing the western boundary of the Territory. This was as follows:

AN ACT to fix the western boundary line of the Territory of Arkansas, and for other purposes.

The western boundary line^o of the Territory of Arkansas shall begin at a point forty miles west of the southwest corner of the State of Missouri and run south to the right bank of the Red River, and thence down the river and with the Mexican boundary to the line of the State of Louisiana.

Four years later, in 1828, the following act was passed defining its southern boundary:

AN ACT to authorize the President of the United States to run and mark a line dividing the Territory of Arkansas from the State of Louisiana.

Commencing on the right bank of the Mississippi River at latitude thirty-three degrees north and running due west on that parallel of latitude to where a line running due north from latitude thirty-two degrees north on the Sabine River will intersect the same.

The same year the following treaty changed materially the western line of the Territory, placing it in its present position.

TREATY WITH THE, CHEROKEE INDIANS MAY 28, 1828.

ARTICLE 1.—The western boundary of Arkansas shall be, and the same is, hereby defined, viz: A line shall be run, commencing on Red River at the point where the Eastern Choctaw line strikes said river, and run due north with said line to the River Arkansas; thence in a line to the southwest corner of Missouri.

The Eastern Choctaw line, referred to above, starts on the Arkansas River, "one hundred paces west of Fort Smith, and thence due south to the Red River." (Treaty with Choctaw Nation, January 20, 1825.)

Arkansas was admitted as a State June 15, 1836.

The following extracts from the enabling act, and from various constitutions, give statements of the boundaries, differing slightly from one another, but, for the most part, only in wording:

CONSTITUTION OF ARKANSAS, 1836.

Beginning in the middle of the main channel of the Mississippi River on the parallel of 36 degrees north latitude; running from thence west with the parallel of latitude to the Saint Francis River; thence up the middle of the main channel of said river to the parallel of thirty-six degrees thirty minutes north; from thence west to the southwest corner of the State of Missouri; and from thence to be bounded on the west to the north bank of Red River, as by acts of Congress and treaties heretofore defining the western limits of the Territory of Arkansas, and to be bounded on the south side of Red River by the Mexican boundary line to the northwest corner of the State of Louisiana; thence east by the Louisiana state line to the middle of the main channel of the Mississippi River; thence up the middle of the main channel of said river to the thirty-sixth degree of north latitude, the point of beginning.

Again, in the enabling act for Arkansas, 1836 (Twenty-fourth Congress, first session), the boundaries are found to be defined as follows:

Beginning in the middle of the main channel of the Mississippi River, on the parallel of thirty-six degrees north latitude, running from thence west, with the said parallel of latitude, to the St. Francis River; thence up the middle of the main channel of said river to the parallel of thirty-six degrees thirty minutes north; from thence west to the southwest corner of the State of Missouri; and from thence to be bounded on the west, to the north bank of Red River, by the line described in the first article of the treaty between the United States and the Cherokee Nation of Indians, west of the Mississippi, made and concluded at the city of Washington, on the twenty-sixth day of May, in the year of our Lord one thousand eight hundred and twenty-eight; and to be bounded on the south side of Red River by the Mexican boundary line to the northwest corner of the State of Louisiana; thence east with the Louisiana state line to the middle of the main channel of the Mississippi River; thence up the middle of the main channel of the said river to the thirty-sixth degree of north latitude, the point of beginning.

In the constitution of 1864 the boundaries are defined as follows:

Beginning in the middle of the Mississippi River, on the parallel of thirty-six degrees north latitude, to the St. Francis River; thence up the middle of the main channel of said river to the parallel of thirty-six degrees thirty minutes north, thence west to the southwest corner of the State of Missouri; and from thence to be bounded on the west to the north bank of Red River, as by acts of Congress of the United States, and the treaties heretofore defining the western limits of the Territory of Arkansas; and to be bounded on the south side of Red River by the boundary line of the State of Texas, to the northwest corner of the State of Louisiana; thence east with the Louisiana state line to the middle of the main channel of the Mississippi River;

thence up the middle of the main channel of said river to the thirty-sixth degree of north latitude, the point of beginning.

The constitution of 1868 differs but slightly from the last. It is as follows:

Beginning at the middle of the main channel of the Mississippi River, on the parallel of 36° north latitude, running from thence west, with the said parallel of latitude, to the Saint Francis River; thence up the middle of the main channel of said river to the parallel of $36^{\circ} 30'$ north; from thence west with the boundary line of the State of Missouri to the southwest corner of that State; and thence to be bounded on the west to the north bank of Red River, as by acts of Congress and treaties heretofore defining the western limits of the Territory of Arkansas; and to be bounded on the south side of Red River by the boundary line of the State of Texas to the northwest corner of the State of Louisiana; thence east with the Louisiana State line to the middle of the main channel of the Mississippi River; thence up the middle of the main channel of said river, including an island in said river known as "Belle Point Island," to the 36° of north latitude, the place of beginning.

In the constitution of 1874 there are again slight differences, mainly in wording.

Beginning at the middle of the main channel of the Mississippi River, on the parallel of thirty-six degrees of north latitude; running thence west with said parallel of latitude to the middle of the main channel of the Saint Francis River; thence up the main channel of said last-named river to the parallel of thirty-six degrees thirty minutes of north latitude; thence west with the southern boundary line of the State of Missouri to the southwest corner of said last-named State; thence to be bounded on the west to the north bank of Red River, as by act of Congress and treaties existing January 1, 1837, defining the western limits of the Territory of Arkansas and to be bounded across and south of Red River by the boundary line of the State of Texas as far as to the northwest corner of the State of Louisiana; thence easterly with the northern boundary line of said last-named State, to the middle of the main channel of the Mississippi River; thence up the middle of the main channel of said last-named river, including an island in said river known as "Belle Point Island," and all other land originally surveyed and included as a part of the Territory or State of Arkansas to the thirty-sixth degree of north latitude, the place of beginning.

TENNESSEE.

Tennessee was originally a part of North Carolina. (For further information *vide* North Carolina, p. 92.)

In 1790 it was ceded to the United States. Its boundaries described in the act of cession are, substantially, those of the present day.

On June 1, 1796, by an act of Congress it was admitted into the Union.

The act of admission declares its boundaries, as "All the territory ceded by North Carolina."

(For the history of the eastern boundary *vide* North Carolina, p. 94; for the southern boundary *vide* Georgia, p. 99, Alabama, p. 103, and Mississippi, p. 103.)

The Mississippi River forms its western boundary under the treaty of peace of 1783.

The line which divided Virginia and North Carolina was the southern boundary of Kentucky. Virginia and North Carolina, prior to the creation of the States of Kentucky and Tennessee, appointed commissioners, Messrs. Walker and Henderson, to run and mark the line on the parallel of latitude $36^{\circ} 30'$. From a point on the top of the Cumberland Mountains, now the southeastern corner of Kentucky, Walker ran and marked the line to a point on the Tennessee River. This line, called Walker's line, was regarded for many years as the dividing line between Kentucky and Tennessee. It was ascertained, however, that Walker's line was north of latitude $36^{\circ} 30'$.

The Indian title to the land west of the Tennessee River being extinguished by the treaty of 1819, the legislature appointed Robert Alexander and Luke Munsell to ascertain the true point of latitude $36^{\circ} 30'$ on the Mississippi River, and to run and mark a line east on that parallel, which was done as far east as the Tennessee River. (For above, see Gen. Stat. Ky., 1873, p. 167.)

In 1820 commissioners were appointed by Kentucky and Tennessee, respectively, to settle the boundary. Their report was ratified, and is as follows, viz :

ART. I. The line of boundary and separation between the States of Kentucky and Tennessee shall be as follows, viz :

The line run by the Virginia commissioners in the year 1779-'80, commonly called Walker's line, as the same is reputed, understood, and acted upon by the said States, their respective officers and citizens, from the southeastern corner of Kentucky to the Tennessee River; thence with and up said river to the point where the line of Alexander and Munsell, run by them in the last year under the authority of an act of the legislature of Kentucky entitled "An act to run the boundary line between this State and the State of Tennessee, west of the Tennessee River, approved Feb. 8, 1819," would cross said river, and thence with the said line of Alexander and Munsell, to the termination thereof on the Mississippi River below New Madrid.

Then follow nine other articles.

Article III provides for running and marking the line at any subsequent time. (See General Stat. Kentucky, page 170.)

In 1858-'59 commissioners were appointed by Kentucky and Tennessee to run this line.

The detailed report can be found in Statutes of Tennessee, 1871, Vol. I, pages 223-243, giving courses, bearings, mile-stones erected, and a map of the boundary.

(For a history of the boundary between Virginia and Tennessee, *vide* Virginia, p. 91.)

KENTUCKY.

Kentucky was included in the original limits of Virginia, and was a part of the county of Augusta. Augusta County was formed in 1738. In 1769 Botetourt County was created from a portion of Augusta County; in 1772, Fincastle from Botetourt; in 1776, Kentucky from Fincastle.

The boundaries of all these counties may be found in Hening's *Laws of Virginia*, Vols. I to IX.

In 1789 Virginia passed an act giving her consent that the county of Kentucky, within her jurisdiction, should be formed into a new State. Accordingly, June 1, 1792, Kentucky was admitted into the Union, with substantially her present boundaries.

By the cession of 1784, by Virginia to the United States, of the territory northwest of the Ohio River, this river became the northwest boundary of the State of Kentucky.

The western boundary, the Mississippi, was fixed by the treaty of peace in 1783.

(For a history of the boundary between Kentucky and Virginia and West Virginia, *vide* Virginia, p. 90, for the boundary between Kentucky and Tennessee, *vide* Tennessee, p. 109.)

OHIO.

Ohio was the first State formed from the original territory northwest of the river Ohio. It was admitted as a State on November 29, 1802, with limits given in the enabling act as follows:

Bounded on the east by the Pennsylvania line, on the south by the Ohio River, to the mouth of the Great Miami River, on the west by the line drawn due north from the mouth of the Great Miami aforesaid, and on the north by an east and west line drawn through the southerly extreme of Lake Michigan, running east after intersecting the due-north line aforesaid; from the mouth of the Great Miami until it shall intersect Lake Erie or the territorial line; and thence with the same through Lake Erie to the Pennsylvania line aforesaid: *Provided*, That Congress shall be at liberty at any time hereafter either to attach all the territory lying east of the line to be drawn due north from the mouth of the Miami aforesaid to the territorial line, and north of an east and west line drawn through the southerly extreme of Lake Michigan, running east as aforesaid to Lake Erie, to the aforesaid State, or dispose of it otherwise, in conformity to the fifth article of compact between the original States and the people and States to be formed in the territory northwest of the river Ohio. (Seventh Congress, first session.)

In the constitution of Ohio of 1802, Article VII, the boundaries are defined as follows:

Bounded on the east by the Pennsylvania line; on the south by the Ohio River, to the mouth of the Great Miami River; on the west by the line drawn due north from the mouth of the great Miami aforesaid; and on the north by an east and west line drawn through the southerly extreme of Lake Michigan, running east after intersecting the due north line aforesaid from the mouth of the Great Miami, until it shall intersect Lake Erie or the territorial line; and thence with the same through Lake Erie to the Pennsylvania line aforesaid; provided always, and it is hereby fully understood and declared by this convention, that if the southerly bend or extreme of Lake Michigan should extend so far south that a line drawn due east from it should

not intersect Lake Erie, or if it should intersect the said Lake Erie east of the mouth of the Miami River of the Lake, then, and in that case, with the assent of the Congress of the United States, the northern boundary of this State shall be established by, and extending to, a direct line running from the southern extremity of Lake Michigan to the most northerly cape of the Miami Bay, after intersecting the due north line from the mouth of the Great Miami River as aforesaid; thence northeast to the territorial line, and by the said territorial line to the Pennsylvania line.

In accordance with the provisions in the enabling act, and in the first constitution of the State, the northern boundary of the State was changed so that, instead of running on a parallel drawn from the southern extremity of Lake Michigan, it followed the arc of a great circle drawn from the southern extremity of Lake Michigan to the most northern cape of Maumee ("Miami") Bay.

Following are the text of the act providing for the examination of the northern boundary and that of the act making the change in the boundary.

AN ACT to provide for the taking of certain observations preparatory to the adjustment of the northern boundary line of the State of Ohio.

That the President of the United States cause to be ascertained, by accurate observation, the latitude and longitude of the southerly extreme of Lake Michigan; and that he cause to be ascertained, by like observation, the point on the Miami of the Lake which is due east therefrom, and also the latitude and longitude of the most northerly cape of the Miami Bay; also, that he cause to be ascertained, with all practicable accuracy, the latitude and longitude of the most southerly point in the northern boundary line of the United States in Lake Erie, and also the points at which a direct line drawn from the southerly extreme of Lake Michigan to the most southerly point in said northern boundary line of the United States will intersect the Miami River and Bay; and also that he cause to be ascertained, by like observation, the point in the Mississippi which is due west from the southerly extreme of Lake Michigan; and that the said observations be made and the result thereof returned to the proper Department within the current year. (Twenty-second Congress, first session, 1832.)

AN ACT to establish the northern boundary line of the State of Ohio, and to provide for the admission of the State of Michigan into the Union.

The northern boundary line of the State of Ohio shall be established at and shall be a direct line drawn from the southern extremity of Lake Michigan to the most northerly cape of the Maumee (Miami) Bay after that line, so drawn, shall intersect the eastern boundary line of the State of Indiana; and from the said north cape of the said bay northeast to the boundary line between the United States and the province of Upper Canada, in Lake Erie, and thence, with the said last-mentioned line, to its intersection with the western line of the State of Pennsylvania. (Twenty-fourth Congress, first session, 1836.)

INDIANA.

By the act passed in the year 1800, to take effect on and after the 4th day of July of that year, the Territory Northwest of the River Ohio was divided into two parts, the eastern part to retain the old name, the western part to become the Territory of Indiana.

Under this act the Territory of Indiana was organized. The description of the boundary line between these two Territories is given in the following act establishing them :

That from and after the fourth day of July next all that part of the territory of the United States northwest of the Ohio River, which lies to the westward of a line beginning at the Ohio, opposite to the mouth of Kentucky River, and running thence to Fort Recovery, and thence north until it shall intersect the territorial line between the United States and Canada, shall, for the purpose of temporary government, constitute a separate Territory, and be called Indiana Territory.

SEC. 5. That whenever that part of the territory of the United States which lies to the eastward of a line beginning at the mouth of the Great Miami River, and running thence due north to the territorial line between the United States and Canada, shall be erected into an independent State, and admitted into the Union on an equal footing with the original States, thenceforth said line shall become and remain permanently the boundary line between such State and the Indiana Territory, anything in this act contained to the contrary notwithstanding. (Sixth Congress, first session.)

Ohio was admitted in 1802. Its western boundary, a meridian through the mouth of the Miami River, left a narrow strip of country between Ohio and the Territory of Indiana, which was by a clause in the enabling act of Ohio added to Indiana Territory. The following is the clause in question :

SEC. 3. All that part of the territory of the United States northwest of the river Ohio heretofore included in the eastern division of said Territory, and not included within the boundary herein prescribed for the said State, is hereby attached to and made a part of the Indiana Territory.

On the 30th of June, 1805, the northern portion of Indiana Territory was cut off and organized as Michigan Territory. (For the divisional line between these, see Michigan, p. 113.)

On March 1, 1809, Indiana Territory was divided, and the western portion of it organized as Illinois Territory. (For a description of the divisional line between these two Territories, see Illinois, p. 113.) On December 11, 1816, Indiana was admitted as a State with the limits as given in the following extract from the enabling act, which have not since been changed :

AN ACT to enable the people of the Indiana Territory to form a constitution and State government, and for the admission of such State into the Union on an equal footing with the original States.

The said State shall consist of all the territory included within the following boundaries, to wit: Bounded on the east by the meridian line which forms the western boundary of the State of Ohio; on the south by the river Ohio from the mouth of the Great Miami River to the mouth of the river Wabash; on the west by a line drawn along the middle of the Wabash from its mouth to a point where a due north line drawn from the town of Vincennes would last touch the northwestern shore of the said river; and from thence by a due north line, until the same shall intersect an east and west line drawn through a point 10 miles north of the southern extreme of Lake Michigan; on the north by the said east and west line until the same shall intersect the first-mentioned meridian line which forms the western boundary of the State of Ohio. (Fourteenth Congress, first session.)

ILLINOIS.

Illinois Territory, originally part of the Northwest Territory, and subsequently a part of Indiana Territory, was organized on March 1, 1809. The following clause from the act separating it from Indiana Territory; defines its boundary :

AN ACT for dividing the Indiana Territory into two separate governments.

From and after the first day of March next, all that part of the Indiana Territory which lies west of the Wabash River and a direct line drawn from the said Wabash River and Post Vincennes due north to the territory line between the United States and Canada shall, for the purpose of temporary government, constitute a separate Territory and be called Illinois. (Tenth Congress, second session.)

On December 3, 1818, it was admitted as a State, with its present boundaries. The enabling act defines these boundaries as follows :

AN ACT to enable the people of the Illinois Territory to form a constitution and State government, and for the admission of such State into the Union on an equal footing with the original States.

The said State shall consist of all the territory included within the following boundaries, to wit: Beginning at the mouth of the Wabash River; thence up the same and with the line of Indiana to the northwest corner of said State; thence east with the line of the same State to the middle of Lake Michigan; thence north along the middle of said lake to north latitude forty-two degrees thirty minutes; thence west to the middle of the Mississippi River; and thence down along the middle of that river to its confluence with the Ohio River; and thence up the latter river along its northwestern shore to the beginning. (Fifteenth Congress, second session.)

MICHIGAN.

Michigan was organized as a Territory June 30, 1805, from the northern part of Indiana Territory.

The following clause from the act dividing Indiana Territory defines its limits :

From and after the thirtieth day of June next all that part of the Indiana Territory which lies north of a line drawn east from the southerly bend or extreme of Lake Michigan, until it shall intersect Lake Erie, and east of a line drawn from the said southerly bend through the middle of said lake to its northern extremity, and thence due north to the northern boundary of the United States, shall, for the purpose of temporary government, constitute a separate Territory, and be called Michigan. (Eighth Congress, second session.)

The enabling act for Illinois, passed in 1818, contained a provision transferring to the Territory of Michigan the portion of the Territory of Illinois not included in the State of that name. The following is the text of the clause referred to :

All that part of the territory of the United States lying north of the State of Indiana, and which was included in the former Indiana Territory, together with that part of the Illinois Territory which is situated north of and not included within the bound-

aries prescribed by this act, to the State thereby authorized to be formed, shall be, and hereby is, attached to and made a part of the Michigan Territory, from and after the formation of the said State.

In 1834 an act was passed extending the limits of the Territory of Michigan to the Missouri River.

The clause of this act relating to area is as follows:

AN ACT to attach the territory of the United States west of the Mississippi River and north of the State of Missouri to the Territory of Michigan.

All that part of the territory of the United States bounded on the east by the Mississippi River, on the south by the State of Missouri and a line drawn due west from the northwest corner of said State to the Missouri River; on the southwest and west by the Missouri River and the White Earth River, falling into the same; and on the north by the northern boundary of the United States, shall be, and hereby is, for the purpose of temporary government, attached to and made a part of the Territory of Michigan.

In 1836 Wisconsin Territory was formed from that part of Michigan Territory lying west of the present limits of the State of that name. (*Vide* Wisconsin, p. 115.)

Reduced to its present limits, as described in the following clause from its enabling act, Michigan was admitted to the Union January 26, 1837:

AN ACT to provide for the admission of the State of Michigan into the Union.

Beginning at the point where the above-described northern boundary of the State of Ohio intersects the eastern boundary of the State of Indiana, and running thence with the said boundary line of Ohio, as described in the first section of this act, until it intersects the boundary line between the United States and Canada in Lake Erie; thence with the said boundary line between the United States and Canada through the Detroit River, Lake Huron, and Lake Superior, to a point where the said line last touches Lake Superior; thence in a direct line through Lake Superior to the mouth of the Montreal River; thence through the middle of the main channel of the said river Montreal to the middle of the Lake of the Desert; thence in a direct line to the nearest headwater of the Menomonee River; thence through the middle of that fork of the said river first touched by the said line to the main channel of the said Menomonee River; thence down the center of the main channel of the same to the center of the most usual ship channel of the Green Bay of Lake Michigan; thence through the center of the most usual ship channel of the said bay to the middle of Lake Michigan; thence through the middle of Lake Michigan to the northern boundary of the State of Indiana, as that line was established by the act of Congress of the nineteenth of April, eighteen hundred and sixteen; thence due east with the north boundary line of the said State of Indiana to the northeast corner thereof; and thence south, with the east boundary line of Indiana, to the place of beginning. (Twenty-fourth Congress, first session.)

The above boundaries remain unchanged.

WISCONSIN.

Wisconsin was organized as a Territory July 3, 1836. As originally constituted its area comprised all that part of the former Territory of

Michigan which lay outside of the present limits of the State of Michigan. The limits are defined in the act for its organization as follows:

Bounded on the east by a line drawn from the northeast corner of the State of Illinois, through the middle of Lake Michigan, to a point in the middle of said lake and opposite the main channel of Green Bay, and through said channel and Green Bay to the mouth of the Menomonee; thence through the middle of the main channel of said river to that head of said river nearest to the Lake of the Desert; thence in a direct line to the middle of said lake; thence through the middle of the main channel of the Montreal River to its mouth; thence with a direct line across Lake Superior to where the territorial line of the United States last touches said lake northwest; thence on the north with the said territorial line to the White Earth River, on the west by a line from the said boundary line following down the middle of the main channel of White Earth River to the Missouri River, and down the middle of the main channel of the Missouri River to a point due west from the northwest corner of the State of Missouri, and on the south, from said point, due east to the northwest corner of the State of Missouri; and thence with the boundaries of the States of Missouri and Illinois, as already fixed by acts of Congress. (Twenty-fourth Congress, first session.)

In 1838 all that part of the territory lying west of the Mississippi and a line drawn due north from its source to the international boundary—that is, all that part which was originally comprised in the Louisiana purchase—was organized as the Territory of Iowa. (See Iowa, p. 117.)

On August 9, 1846, an enabling act for Wisconsin was passed giving the boundaries as follows:

Beginning at the northeast corner of the State of Illinois, that is to say, at a point in the center of Lake Michigan where the line of forty-two degrees and thirty minutes of north latitude crosses the same; thence running with the boundary line of the State of Michigan, through Lake Michigan, Green Bay, to the mouth of the Menomonee River; thence up the channel of said river to the Brulè River; thence up said last-mentioned river to Lake Brulè; thence along the southern shore of Lake Brulè in a direct line to the center of the channel between Middle and South Islands in the Lake of the Desert; thence in a direct line to the headwaters of Montreal River, as marked upon the survey made by Captain Cramm; thence down the main channel of the Montreal River to the middle of Lake Superior; thence through the center of Lake Superior to the mouth of the Saint Louis River, thence up the main channel of said river to the first rapids in the same, above the Indian village, according to Nicollet's map; thence due south to the main branch of the river Saint Croix; thence down the middle of the main channel of said river to the Mississippi; thence down the center of the main channel of that river to the northwest corner of the State of Illinois; thence due east with the northern boundary of the State of Illinois to the place of beginning. (Twenty-ninth Congress, first session.)

On March 3, 1847, a supplementary act for the admission of Wisconsin was passed by Congress, in which the western boundary of the proposed State was changed as follows:

That the assent of Congress is hereby given to the change of boundary proposed in the first article of said constitution, to wit: Leaving the boundary line prescribed in the act of Congress entitled "An act to enable the people of Wisconsin Territory to form a constitution and State government, and for the admission of such State into the Union," at the first rapids in the river St. Louis; thence in a direct line southwardly to a point fifteen miles east of the most easterly point of Lake St. Croix;

thence due south to the main channel of the Mississippi River or Lake Pepin; thence down the said main channel, as prescribed in said act. (Twenty-ninth Congress, second session.)

On May 29, 1848, Wisconsin was admitted into the Union.

MISSOURI.

The name of the Territory of Louisiana was changed in 1812 to Missouri, by act of Congress. At that time the Territory comprised all of the original Louisiana purchase, excepting the State of Louisiana, which had been formed from it. The Territory of Arkansas, with limits very similar to those of the present State, was formed from it in 1819. On August 10, 1821, the *State of Missouri* was formed and admitted, with limits, excepting as to the northwest corner, the same as at present.

Boundaries are defined as follows:

Beginning in the middle of the Mississippi River, on the parallel of thirty-six degrees of north latitude; thence west along that parallel of latitude to the Saint Francois River; thence up, and following the course of that river, in the middle of the main channel thereof, to the parallel of latitude of thirty-six degrees and thirty minutes; thence west, along the same, to a point where the said parallel is intersected by a meridian-line passing through the middle of the mouth of the Kansas River, where the same empties into the Missouri River; thence from the point aforesaid north, along the said meridian line to the intersection of the parallel of latitude which passes through the rapids of the river Des Moines, making the said line to correspond with the Indian boundary line; thence east from the point of intersection last aforesaid, along the said parallel of latitude, to the middle of the channel of the main fork of the said river Des Moines; thence down and along the middle of the main channel of the said River Des Moines to the mouth of the same where it empties into the Mississippi River; thence due east to the middle of the main channel of the Mississippi River; thence down and following the course of the Mississippi River in the middle of the main channel thereof, to the place of beginning. (Sixteenth Congress, first session.)

In 1836 the boundaries were extended on the northwest to the Missouri River, as described in the following act of the legislature amendatory to the constitution of 1820:

That the boundary of the State be so altered and extended as to include all that tract of land lying on the north side of the Missouri River and west of the present boundary of this State, so that the same shall be bounded on the south by the middle of the main channel of the Missouri River, and on the north by the present northern boundary line of the State, as established by the constitution, when the same is continued in a right line to the west, or to include so much of said tract of land as Congress may assent.

This was ratified by Congress in the following act:

AN ACT to extend the western boundary of the State of Missouri to the Missouri River.

That when the Indian title to all the lands lying between the State of Missouri and the Missouri River shall be extinguished, the jurisdiction over said lands shall be hereby ceded to the State of Missouri, and the western boundary of said State shall be then extended to the Missouri River. (Twenty-fourth Congress, first session.)

The territory remaining after the formation of the State bore the name of Missouri for many years thereafter. Meanwhile, however, it was reduced by the formation of several Territories which were carved from its area. In 1834, the part north of the State of Missouri and east of the Missouri and White Earth Rivers was annexed to the territory of Michigan. (For further history of this portion, *vide* Michigan, p. 114; Iowa, below; Minnesota, p. 118; and Dakota, p. 121.) In 1854 Kansas and Nebraska Territories were formed, absorbing the remainder. (*Vide* Kansas, p. 119, and Nebraska, p. 120.)

The following are the boundaries of Missouri as at present established: The east boundary is the mid-channel of the Mississippi River from the mouth of the Des Moines to its point of intersection with the thirty-sixth parallel of latitude; the south boundary begins at the latter point and runs west on the parallel of 36 degrees of latitude to the Saint Francis River, thence up the mid-channel of that river to the parallel of latitude 36° 30', thence west on that parallel to its intersection by a meridian passing through the middle of the mouth of the Kansas River; the west boundary is the last mentioned meridian as far north as the mouth of the Kansas River, thence it follows northwestward the mid-channel of the Missouri River to the parallel of latitude 40° 30'; the north boundary is the last-mentioned parallel as far east as its point of intersection with the Des Moines River, whence it follows the mid-channel of the Des Moines River southward to its mouth.

IOWA.

Iowa was organized as a Territory on July 3, 1838, being formed from a portion of Wisconsin Territory. The limits were defined as follows in the act creating it:

All that part of the present Territory of Wisconsin which lies west of the Mississippi River and west of the line drawn due north from the headwaters or sources of the Mississippi to the Territorial line. (Twenty-fifth Congress, second session. See Wisconsin, p. 115.)

The following clause from an act passed in 1839 is supplementary to the above act:

AN ACT to define and establish the eastern boundary line of the Territory of Iowa.

That the middle or centre of the main channel of the river Mississippi shall be deemed, and is hereby declared, to be the eastern boundary line of the Territory of Iowa, so far or to such extent as the said Territory is bounded eastwardly by or upon said river. (Twenty-fifth Congress, third session.)

Iowa was admitted to the Union on March 3, 1845. As originally constituted the limits of the State were quite different from those which it has at present.

The following extract from the enabling act gives the original limits:

That the following shall be the boundaries of the said State of Iowa, to wit: Beginning at the mouth of the Des Moines River at the middle of the Mississippi; thence by the middle of the channel of that river to a parallel of latitude passing through the mouth of the Mankato, or Blue Earth River; thence west along the said parallel of latitude to a point where it is intersected by a meridian line, seventeen degrees and thirty minutes west of the meridian of Washington City; thence due south to the northern boundary line of the State of Missouri; thence eastwardly following that boundary to the point at which the same intersects the Des Moines River; thence by the middle of the channel of that river to the place of beginning. (Twenty-eighth Congress, second session.)

On December 28, 1846, an act was passed changing the boundaries of the State and giving it its present limits.

The following extract from the act defines the boundaries as at present constituted:

Beginning in the middle of the main channel of the Mississippi River, at a point due east of the middle of the mouth of the main channel of the Des Moines River; thence up the middle of the main channel of the said Des Moines River, to a point on said river where the northern boundary line of the State of Missouri, as established by the constitution of that State, adopted June twelfth, eighteen hundred and twenty, crosses the said middle of the main channel of the said Des Moines River; thence westwardly along the said northern boundary line of the State of Missouri, as established at the time aforesaid, until an extension of said line intersect the middle of the main channel of the Missouri River, to a point opposite the middle of the main channel of the Big Sioux River, according to Nicollet's map; thence up the main channel of the said Big Sioux River, according to said map, until it is intersected by the parallel of forty-three degrees and thirty minutes north latitude; thence east along said parallel of forty-three degrees and thirty minutes, until said parallel intersect the middle of the main channel of the Mississippi River; thence down the middle of the main channel of said Mississippi River, to the place of beginning.

MINNESOTA.

The Territory of Minnesota was organized on March 3, 1849, and originally comprised the portion of the former Territory of Iowa, outside of the limits of the present State of Iowa, extending east to the west boundary line of Wisconsin. The terms of the act creating this Territory, so far as they relate to its boundary, are as follows:

All that part of the territory of the United States which lies within the following limits, to wit: Beginning in the Mississippi River, at the point where the line of forty-three degrees and thirty minutes of north latitude crosses the same; thence running due west on said line, which is the northern boundary of the State of Iowa, to the northwest corner of the said State of Iowa; thence southerly, along the western boundary of said State, to the point where said boundary strikes the Missouri River; thence up the middle of the main channel of the Missouri River to the mouth of the White Earth River; thence up the middle of the main channel of the White Earth River to the boundary line between the possessions of the United States and Great Britain, to Lake Superior; thence along the western boundary line of said State

of Wisconsin to the Mississippi River; thence down the main channel of said river to the place of beginning." (Thirtieth Congress, second session.)

Minnesota was admitted as a State on May 11, 1858, with the same boundaries which it has at present. These are given in the enabling act as follows:

Beginning at the point in the center of the main channel of the Red River of the North where the boundary line between the United States and the British Possessions crosses the same; thence up the main channel of said river to that of the Bois des Sioux River; thence up the main channel of said river to Lake Traverse; thence up the center of said lake to the southern extremity thereof; thence in a direct line to the head of Big Stone Lake; thence through its center to its outlet; thence by a due south line to the north line of the State of Iowa; thence east along the northern boundary of said State to the main channel of the Mississippi River; thence up the main channel of said river, and following the boundary line of the State of Wisconsin until the same intersects the Saint Louis River; thence down said river to and through Lake Superior, on the boundary line of Wisconsin and Michigan, until it intersects the dividing line between the United States and the British Possessions; thence up Pigeon River, and following said dividing line, to the place of beginning.

KANSAS.

The Territory of Kansas was organized on May 30, 1854, from a part of Missouri Territory. The following clause from the act of organization defines its limits:

SECTION 19. All that part of the territory of the United States included within the following limits, except such portions thereof as are hereinafter expressly exempted from the operations of this act, to wit: Beginning at a point on the western boundary of the State of Missouri, where the thirty-seventh parallel of north latitude crosses the same; thence west on said parallel to the eastern boundary of New Mexico; thence north on said boundary to latitude thirty-eight; thence following said boundary westward to the east boundary of the Territory of Utah, on the summit of the Rocky Mountains; thence northward on said summit to the fortieth parallel of latitude; thence east on said parallel to the western boundary of the State of Missouri; thence south with the western boundary of said State to the place of beginning, be, and the same is hereby, created into a temporary government by the name of the Territory of Kansas.

A portion of this Territory was given up to Colorado at the time of its formation in 1861. (*Vide* Colorado, p. 123.)

Kansas was admitted into the Union on January 29, 1861, with its present boundaries, which are thus defined in the enabling act:

The said State shall consist of all the territory included within the following boundaries, to wit: Beginning at a point on the western boundary of the State of Missouri, where the thirty-seventh parallel of north latitude crosses the same; thence west on said parallel to the twenty-fifth meridian of longitude west from Washington; thence north on said meridian to the fortieth parallel of latitude; thence east on said parallel to the western boundary of the State of Missouri; thence south with the western boundary of said State to the place of beginning.

NEBRASKA.

The Territory of Nebraska was formed on May 30, 1854, from the northwestern part of Missouri Territory. Its limits, as originally constituted, are defined as follows in the act of organization :

Beginning at a point in the Missouri River where the fortieth parallel of north latitude crosses the same; thence west on said parallel to the east boundary of the Territory of Utah, on the summit of the Rocky Mountains; thence on said summit northward to the forty-ninth parallel of north latitude; thence east on said parallel to the western boundary of the Territory of Minnesota; thence southward on said boundary to the Missouri River; thence down the main channel of said river to the place of beginning, be, and the same is hereby, created into a temporary government by the name of the Territory of Nebraska. (Thirty-third Congress, first session.)

This area was reduced in 1861 by the formation of the Territories of Colorado and Dakota. (*Vide* Colorado, p. 123, and Dakota, p. 121.)

The State of Nebraska was admitted on March 1, 1867.

Its limits are defined as follows in the enabling act:

That the said State of Nebraska shall consist of all the territory included within the following boundaries, to wit: Commencing at a point formed by the intersection of the western boundary of the State of Missouri with the fortieth degree of north latitude; extending thence due west along said fortieth degree of north latitude to a point formed by its intersection with the twenty-fifth degree of longitude west from Washington; thence north along said twenty-fifth degree of longitude to a point formed by its intersection with the forty-first degree of north latitude; thence west along said forty-first degree of north latitude to a point formed by its intersection with the twenty-seventh degree of longitude west from Washington; thence north along said twenty-seventh degree of west longitude to a point formed by its intersection with the forty-third degree of north latitude; thence east along said forty-third degree of north latitude to the Keyapaha River; thence down the middle of the channel of said river, with its meanderings, to its junction with the Niobrara River; thence down the middle of the channel of said Niobrara River, and following the meanderings thereof, to its junction with the Missouri River; thence down the middle of the channel of said Missouri River, and following the meanderings thereof, to the place of beginning. (Thirty-eighth Congress, first session.)

In 1870 an act was passed to redefine a portion of the boundary between Nebraska and the Territory of Dakota, the pertinent portion of which is as follows:

That so soon as the State of Nebraska, through her legislature, has given her consent thereto, the center of the main channel of the Missouri River shall be the boundary line between the State of Nebraska and Territory of Dakota, between the following points, to wit: Commencing at a point in the center of said main channel, north of the west line of section twenty-four in township twenty-nine north, of range eight east of the sixth principal meridian, and running along the same to a point west of the most northerly portion of fractional section seventeen, of township twenty-nine north, of range nine east of said meridian, in the State of Nebraska, as meandered and shown by the plats and surveys of said sections originally made and now on file in the General Land Office. (Forty-first Congress, second session.)

In 1882 an act was passed transferring to this State from Dakota a small area lying between the Keyapaha River and the forty-third parallel of latitude. The following is the act in question :

Be it enacted, * * * That the northern boundary of the State of Nebraska shall be, and hereby is, subject to the provisions hereinafter contained, extended so as to include all that portion of the Territory of Dakota lying south of the forty-third parallel of north latitude and east of the Keyapaha River and west of the main channel of the Missouri River. (Forty-seventh Congress, first session.)

DAKOTA.

The Territory of Dakota was organized on March 2, 1861, from parts of Minnesota and Nebraska Territories. The following from the act of organization defines its original limits :

All that part of the territory of the United States included within the following limits, namely: Commencing at a point in the main channel of the Red River of the North, where the forty-ninth degree of north latitude crosses the same; thence up the main channel of the same, and along the boundary of the State of Minnesota to Big Stone Lake; thence along the boundary line of the said State of Minnesota to the Iowa line; thence along the boundary line of the State of Iowa to the point of intersection between the Big Sioux and Missouri Rivers; thence up the Missouri River and along the boundary line of the Territory of Nebraska to the mouth of the Niobrara or Running Water River; thence following up the same, in the middle of the main channel thereof, to the mouth of the Keyapaha or Turtle Hill River; thence up said river to the forty-third parallel of north latitude; thence due west to the present boundary of the Territory of Washington; thence along the boundary line of Washington Territory to the forty-ninth degree of north latitude; thence east along said forty-ninth degree of north latitude to the place of beginning be, and the same is, hereby organized into a temporary government by the name of the Territory of Dakota. (Thirty-sixth Congress, second session.)

In 1863 the Territory of Idaho was formed, its area having been taken from Washington, Dakota, and Nebraska. (*Vide* Idaho, p. 127.) In 1882 a small area was transferred to Nebraska. (*Vide* Nebraska, above.)

The following description, compiled from the act relating to Dakota and other Territories formed from its area, gives its present limits:

The east boundary is the main channel of the Red River from the forty-ninth parallel southward to Big Stone Lake; from the center of that lake to its outlet; thence by a due south line to the parallel of latitude 43° 30'; thence west on this parallel until it strikes the Big Sioux River; thence down the mid channel of the Big Sioux River to its mouth. The south boundary is the main channel of the Missouri River until it intersects the forty-third parallel of latitude; thence it follows the forty-third parallel of latitude westward to the twenty-seventh degree of longitude. The west boundary is the twenty-seventh degree of longitude, and the north boundary is the forty-ninth parallel of latitude.

MONTANA.

The Territory of Montana was organized May 26, 1864, from a portion of Idaho. Its limits, which have been changed but slightly, are given in the following extract from the organizing act:

That all that part of the territory of the United States included within the limits to wit: Commencing at a point formed by the intersection of the twenty-seventh degree of longitude west from Washington with the forty-fifth degree of north latitude; thence due west on said forty-fifth degree of latitude to a point formed by its intersection with the thirty-fourth degree of longitude west from Washington; thence due south along said thirty-fourth degree of longitude to its intersection with the forty-fourth degree and thirty minutes of north latitude; thence due west along said forty-fourth degree and thirty minutes of north latitude to a point formed by its intersection with the crest of the Rocky Mountains; thence following the crest of the Rocky Mountains northward till its intersection with the Bitter Root Mountains; thence northward along the crest of said Bitter Root Mountains to its intersection with the thirty-ninth degree of longitude west from Washington; thence along said thirty-ninth degree of longitude northward to the boundary line of the British possessions; thence eastward along said boundary line to the twenty-seventh degree of longitude west from Washington; thence southward along said twenty-seventh degree of longitude to the place of beginning, be, and the same is hereby created into a temporary government by the name of the Territory of Montana. (Thirty-eighth Congress, first session.)

In 1873, Congress, under the erroneous impression that a portion of Dakota remained west of Wyoming, and adjoining Montana, passed an act to attach it to Montana. As, however, no such detached area could by any possibility have existed, the compilers of the Revised Statutes sought to give the act effect by shifting a portion of the southern boundary of Montana from the parallel of $44^{\circ} 30'$ to the continental watershed, thereby reducing Montana's area. The following is the act referred to:

AN ACT to readjust the western boundary of Dakota Territory.

That all that portion of Dakota Territory lying west of the one hundred and eleventh meridian of longitude which, by an erroneous definition of the boundaries of said Territory by a former act of Congress, remains detached and distant from Dakota proper some two hundred miles, be and the same is hereby attached to the adjoining territory of Montana. (Forty-second Congress, third session.)

The boundaries of Montana are as follows: Beginning at the intersection of the twenty-seventh meridian of longitude with the boundary line between the United States and the British possessions, it follows said meridian south to the forty-fifth parallel of latitude, thence west on this parallel to the thirty-fourth meridian, south on the thirty-fourth meridian to the point where that meridian intersects the continental watershed, thence westward and northwestward following the line of the continental watershed and the summit of the Bitter Root range, to its intersection with the thirty-ninth meridian, thence north on the thirty-ninth meridian to the boundary line between the United States and British possessions and east on that boundary line to the point of beginning.

WYOMING.

Wyoming was organized as a Territory on July 25, 1868, from territory previously comprised in the Territory of Idaho. Its limits, which are the same as originally constituted, are defined in the following clause from the act creating the Territory :

That all that part of the United States described as follows: Commencing at the intersection of the twenty-seventh meridian of longitude west from Washington with the forty-fifth degree of north latitude, and running thence west to the thirty-fourth meridian of west longitude, thence south to the forty-first degree of north latitude, thence east to the twenty-seventh meridian of west longitude, and thence north to the place of beginning, be, and the same is hereby, organized into a temporary government by the name of the Territory of Wyoming. (Fortieth Congress, second session.)

COLORADO.

Colorado was organized as a Territory on February 28, 1861, with the limits which it has at present, being made from portions of Utah, New Mexico, Kansas, and Nebraska.

On August 1, 1876, it was admitted as a State.

The following clause from the enabling act gives its limits:

AN ACT to enable the people of Colorado to form a constitution and State government, and for the admission of such State into the Union on an equal footing with the original States.

SEC. 2. That the said State of Colorado shall consist of all the territory included within the following boundaries, to wit: Commencing at a point formed by the intersection of the thirty-seventh degree of north latitude with the twenty-fifth degree of longitude west from Washington; extending thence due west along said thirty-seventh degree of north latitude to a point formed by its intersection with the thirty-second degree of longitude west from Washington; thence due north along said thirty-second degree of west longitude to a point formed by its intersection with the forty-first degree of north latitude; thence due east along said forty-first degree of north latitude to a point formed by its intersection with the twenty-fifth degree of longitude west from Washington; thence due south along said twenty-fifth degree of west longitude. (Thirty-eighth Congress, first session.)

NEW MEXICO.

New Mexico was organized as a Territory on December 13, 1850. Its original area formed a part of the region transferred by Mexico to the United States by the treaty of Guadalupe Hidalgo and by Texas. It was subsequently enlarged by the Gadsden Purchase, (*Vide* pp. 21 and 22.) The formation of Colorado Territory in 1861 and of Arizona in 1863 reduced its area to its present limits. (*Vide* Colorado, above, and Arizona, p. 125.)

The following clause from the act creating the Territory gives its original limits:

SECTION 2. And be it further enacted, That all that portion of the territory of the United States bounded as follows: Beginning at a point in the Colorado River, where the boundary line with the Republic of Mexico crosses the same; thence eastwardly with the said boundary line to the Rio Grande; thence following the main channel of said river to the parallel of the thirty-second degree of north latitude; thence east with said degree to its intersection with the one hundred and third degree of longitude west of Greenwich; thence north with said degree of longitude to the parallel of thirty-eighth degree of north latitude; thence west with said parallel to the summit of the Sierra Madre; thence south with the crest of said mountains to the thirty-seventh parallel of north latitude; thence west with said parallel to its intersection with the boundary line of the State of California; thence with said boundary line to the place of beginning—be, and the same is hereby, erected into a temporary government by the name of the Territory of New Mexico. (Thirty-first Congress, first session.)

The present boundaries of New Mexico are as follows: Beginning at the point of intersection of the one hundred and third meridian of longitude west of Greenwich with the thirty-seventh parallel of latitude, running thence south to its point of intersection with the thirty-second parallel of latitude; thence west on this parallel to its intersection with the Rio Grande; thence southerly down the main channel of the Rio Grande to its point of intersection with the boundary line between the United States and Mexico; thence with this boundary to its intersection with the thirty-second meridian of longitude; thence north along this meridian to the thirty-seventh parallel of latitude, and so along that parallel to the point of beginning.

UTAH TERRITORY.

Utah was organized on September 9, 1850, from territory acquired from Mexico by the treaty of Guadalupe-Hidalgo. Its limits originally extended from the eastern boundary of California to the Rocky Mountains, and from the thirty-seventh to the forty-second parallel. This area was reduced by the formation, in 1861, of the Territories of Nevada (*vide* p. 125) and Colorado (*see* p. 123), and in 1864 and 1866 by the extension eastward of the limits of the State of Nevada (*vide* p. 126).

The following is an extract from the act creating the Territory:

All that part of the territory of the United States included within the following limits, to wit: Bounded on the west by the State of California, on the north by the Territory of Oregon, and on the east by the summit of the Rocky Mountains, and on the south by the thirty-seventh parallel of north latitude, be, and the same is hereby, created into a temporary government, by the name of the Territory of Utah.

The present boundaries of Utah are as follows: Commencing with the intersection of the forty-second parallel of latitude with the thirty-fourth

meridian of longitude, running thence south on this meridian to the forty-first parallel of latitude, thence east on this parallel to the thirty-second meridian of longitude, thence south on this meridian to its intersection with the thirty-seventh parallel of latitude, thence west upon this parallel of latitude to its intersection with the thirty-seventh meridian of longitude, thence north on this meridian to its intersection with the forty-seventh parallel of latitude, thence east on the forty-seventh parallel of latitude, to the point of beginning.

ARIZONA.

Arizona was organized as a Territory on February 24, 1863. Its area was formerly comprised in the Territory of New Mexico. In 1866 a portion of it was cut off and given to the State of Nevada. (*Vide Nevada, below.*) The following clause from the act creating it gives its limits as originally constituted:

That all that part of the present Territory of New Mexico situate west of the line running due south from the point where the southwest corner of the Territory of Colorado joins the northern boundary of the Territory of New Mexico to the southern boundary line of said Territory of New Mexico, be, and the same is hereby, erected into a temporary government by the name of the Territory of Arizona. (For limits of the piece cut off and added to Nevada, see that State.)

The present boundaries of Arizona are as follows: Beginning at the point of intersection of the thirty-seventh parallel of latitude with the thirty-second meridian of longitude; thence south along this meridian to its intersection with the boundary line between the United States and Mexico; thence with this boundary to the Colorado River; thence up the middle of the main channel of the Colorado River to its point of intersection with the thirty-seventh meridian of longitude; north on this meridian to its intersection with the thirty-seventh parallel; and eastward along the thirty-seventh parallel to the point of beginning.

NEVADA.

Nevada, as originally constituted on March 2, 1861, was formed from territory taken from Utah. Its western boundary was made to conform to the eastern boundary of California (*vide California, p. 129*); its northern boundary was, as now, the forty-second parallel; the eastern was the meridian of 39°; and the southern the parallel of 37°. By the enabling act the eastern limit was extended to the thirty-eighth meridian. It was admitted as a State October 31, 1864, with above limits as modified

by the enabling act, and in 1866 its eastern limits were still further extended to longitude 37°, and its southern line established as at present, the latter addition having been made from Arizona.

In the act organizing the Territory the boundaries are defined as follows:

Beginning at the point of intersection of the forty-second degree of north latitude with the thirty-ninth degree of longitude west from Washington; thence running south on the line of said thirty-ninth degree of west longitude until it intersects the northern boundary line of the Territory of New Mexico; thence due west to the dividing ridge separating the waters of Carson Valley from those that flow into the Pacific; thence on said dividing ridge northwardly to the forty-first degree of north latitude; thence due north to the southern boundary of the State of Oregon; thence due east to the place of beginning. (Thirty-sixth Congress, second session.)

The following is the text of that portion of the enabling act relating to boundaries:

SEC. 2. That the said State of Nevada shall consist of all the territory included within the following boundaries, to wit: Commencing at a point formed by the intersection of the thirty-eighth degree of longitude west from Washington with the thirty-seventh degree of north latitude; thence due west along said thirty-seventh degree of north latitude to the eastern boundary line of the State of California; thence in a northwesterly direction along the said eastern boundary line of the State of California to the forty-third degree of longitude west from Washington; thence north along said forty-third degree of west longitude and said eastern boundary line of the State of California to the forty-second degree of north latitude; thence due east along the said forty-second degree of north latitude to a point formed by its intersection with the aforesaid thirty-eighth degree of longitude west from Washington; thence due south down said thirty-eighth degree of west longitude to the place of beginning. (Thirty-eighth Congress, first session.)

The following act makes the addition to its area from Arizona referred to above:

AN ACT concerning the boundaries of the State of Nevada.

That, as provided for and consented to in the constitution of the State of Nevada, all that territory and tract of land adjoining the present eastern boundary of the State of Nevada, and lying between the thirty-seventh and the forty-second degrees of north latitude and west of the thirty-seventh degree of longitude west of Washington, is hereby added to and made a part of the State of Nevada.

SEC. 2. That there is hereby added to and made a part of the State of Nevada all that extent of territory lying within the following boundaries, to wit: Commencing on the thirty-seventh degree of north latitude at the thirty-seventh degree of longitude west from Washington, and running thence south on said degree of longitude to the middle of the river Colorado of the West; thence down the middle of said river to the eastern boundary of the State of California; thence northwesterly along said boundary of California to the thirty-seventh degree of north latitude; and thence east along said degree of latitude to the point of beginning. (Thirty-ninth Congress, first session.)

The present limits of Nevada are as follows:

The east boundary is the thirty-seventh meridian of longitude, extending from the forty-second parallel of latitude southward to its intersection with the middle of the Colorado River; thence following the mid-channel of the Colorado River down to the point where it intersects

the thirty-fifth parallel of latitude; the southwest boundary is the arc of a great circle running from the last-mentioned point and the point of intersection of the one hundred and twentieth degree of longitude west of Greenwich with the thirty-ninth parallel of latitude; the west boundary is the one hundred and twentieth degree of longitude west of Greenwich; the north boundary is the forty-second parallel of latitude.

IDAHO.

The Territory of Idaho was formed March 3, 1863, from parts of Washington, Dakota, and Nebraska. Its original limits, which included, besides the present territory, all of Montana and Wyoming, were given as follows in the act organizing the Territory:

That all that part of the territory of the United States included within the following limits, to wit: Beginning at a point in the middle channel of the Snake River where the northern boundary of Oregon intersects the same; then follow down said channel of Snake River to a point opposite the mouth of the Kooskooskia, or Clearwater River; thence due north to the forty-ninth parallel of latitude; thence east along said parallel to the twenty-seventh degree of longitude west of Washington; thence south along said degree of longitude to the northern boundary of Colorado Territory; thence west along said boundary to the thirty-third degree of longitude west of Washington; thence north along said degree to the forty-second parallel of latitude; thence west along said parallel to the eastern boundary of the State of Oregon; thence north along said boundary to the place of beginning. (Thirty-seventh Congress, third session.)

From this were formed Montana in 1864 (*vide* Montana, p. 122), and Wyoming (*vide* Wyoming, p. 123), in 1868, thereby reducing this territory, with the small addition made in 1873 (*vide* Montana, p. 122), to its present limits.

The present boundary line of Idaho is as follows: Beginning at the intersection of the thirty-ninth meridian with the boundary line between the United States and the British Possessions, it follows said meridian south until it reaches the summit of the Bitter Root Mountains; thence southeastward along the crest of the Bitter Root range and the continental divide until it intersects the meridian of thirty-four degrees of longitude; thence southward on this meridian to the forty-second parallel of latitude; thence west on this parallel of latitude to its intersection with a meridian drawn through the mouth of the Owyhee River; north on this meridian to the mouth of the Owyhee River; thence down the mid-channel of the Snake River to the mouth of the Clearwater; and thence north on the meridian which passes through the mouth of the Clearwater to the boundary line between the United States and the British Possessions; and east on said boundary line to the place of beginning.

OREGON.

Oregon Territory was organized August 14, 1848. The grounds of our title to its area are obscure. In treating with Great Britain for the establishment of our northern boundary west of the Rocky Mountains this region was claimed on three grounds—that of discovery and occupation, the Louisiana purchase, and cession from Spain. On which of these grounds we succeeded in having the boundary established on the forty-ninth parallel will never be ascertained, and is of little moment.

The Territory as originally established extended from the forty-second to the forty-ninth parallel, and from the Pacific Ocean to the crest of the Rocky Mountains, with boundaries defined in the organizing act, as follows:

All that part of the territory of the United States which lies west of the summit of the Rocky Mountains, north of the forty-second degree of north latitude, known as the Territory of Oregon, shall be organized into and constitute a temporary government by the name of the Territory of Oregon. (Thirtieth Congress, first session.)

In 1853 the Territory was reduced by the formation of Washington Territory (*vide* Washington, below), and on February 14, 1859, it was admitted as a State with its present boundaries. These are defined below in an extract from the State constitution:

Beginning one marine league at sea due west from the point where the forty-second parallel of north latitude intersects the same; thence northerly, at the same distance from the line of the coast lying west and opposite the State, including all islands within the jurisdiction of the United States, to a point due west and opposite the middle of the north ship channel of the Columbia River; thence easterly to and up the middle channel of said river, and where it is divided by islands, up the middle of the widest channel thereof, and in like manner up the middle of the main channel of Snake River to the mouth of the Owyhee River; thence due south to the parallel of latitude forty-two degrees north; thence west along said parallel to the place of beginning, including jurisdiction in civil and criminal cases upon the Columbia River and Snake River concurrently with States and Territories of which those rivers form a boundary in common with this State. But the Congress of the United States, in providing for the admission of this State into the Union, may make the said northern boundary conform to the act creating the Territory of Washington.

WASHINGTON TERRITORY.

This was organized March 2, 1853, from a part of Oregon Territory. Its limits, as originally constituted, were as given in the following clause from the act of Congress creating it:

That from and after the passage of this act, all that portion of Oregon Territory lying and being south of the forty-ninth degree of north latitude, and north of the middle of the main channel of the Columbia River from its mouth to where the forty-sixth degree of north latitude crosses said river, near Fort Walla Walla, thence with said forty-sixth degree of latitude to the summit of the Rocky Mountains, be organ-

ized into and constitute a temporary government by the name of the Territory of Washington. (Thirty-second Congress, second session.)

In 1859, on the formation of the State of Oregon, the residue of the Territory of Oregon, being the portion lying east of the present limits of the State, extending thence to the crest of the Rocky Mountains, was added to Washington. This area, with the part of Washington lying east of its present limits, was included in Idaho on the formation of that Territory in 1863.

The present boundaries of Washington Territory are as follows: Beginning on the coast at the mouth of the Columbia River; following up the main channel of the Columbia River to its point of intersection with the forty-sixth parallel of latitude; thence east on the forty-sixth parallel to the Snake River; thence down the main channel of the Snake River to the mouth of the Clearwater; thence north on the meridian which passes through the mouth of the Clearwater to the boundary line between the United States and the British possessions; thence west with that boundary line to the Pacific.

CALIFORNIA.

California was admitted to the Union on September 9, 1850. Its area was taken from territory acquired from Mexico by the treaty of Guadalupe-Hidalgo. Its limits, as defined in the State constitution, are as follows:

Commencing at the point of intersection of forty-second degree of north latitude with the one hundred and twentieth degree of longitude west from Greenwich, and running south on the line of said one hundred and twentieth degree of west longitude until it intersects the thirty-ninth degree of north latitude; thence running in a straight line in a southeasterly direction to the river Colorado, at a point where it intersects the thirty-fifth degree of north latitude; thence down the middle of the channel of said river to the boundary line between the United States and Mexico as established by the treaty of May 30, 1848; thence running west and along said boundary line to the Pacific Ocean, and extending therein three English miles; thence running in a northwesterly direction, and following the direction of the Pacific coast, to the forty-second degree of north latitude; thence on the line of said forty-second degree of north latitude to the place of beginning. Also all the islands, harbors, and bays along and adjacent to the Pacific coast.

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(591)

○

L. C. Graton

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 14

ON THE PHYSICAL CHARACTERISTICS OF THE IRON-CARBURETS
MORE PARTICULARLY ON THE GALVANIC THERMO-ELECTRIC
AND MAGNETIC PROPERTIES OF WROUGHT IRON STEEL
AND CAST IRON IN DIFFERENT STATES OF HARDNESS
TOGETHER WITH A PHYSICAL DIAGRAM FOR
THE CLASSIFICATION OF IRON-CARBURETS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

ADVERTISEMENT.

[Bulletin No. 14.]

The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1883, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed in addition to the number in each case stated, the 'usual number' (1,000) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,000 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. iv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, and VIII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt., U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price \$10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1883. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price \$11.

IV. Comstock Mining and Minerals, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price \$1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price \$1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1882. 4°. xi, 144 pp. 54 l. 54 pl. Price \$1.05.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price \$1.25.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price \$1.10.

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The following are in press, viz:

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. ix, 338 pp. 35 pl.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 56 pl.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. —, — pp. 46 pl.

The following are in preparation, viz:

I. The Precious Metals, by Clarence King.

Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.

Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

Lake Bonneville, by G. K. Gilbert.

Sauropoda, by Prof. O. C. Marsh.

Stegosauria, by Prof. O. C. Marsh.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 14 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining value of Troy ounces of fine metal, etc., by Albert Williams, Jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30', from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 48 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752-1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. A Report of work done in the Washington Laboratory during the fiscal year 1883-'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 185 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

Numbers 1 to 6 of the Bulletins form Volume I, and numbers 7 to 14 Volume II. Volume III is not yet complete.

The following are in press, viz:

15. On the Mesozoic and Cenozoic Paleontology of California, by Dr. C. A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the higher Devonian Faunas of Ontario County, New York, by J. M. Clarke. 1885. 8°. — pp. 3 pl. Price — cents.

17. On the Development of Crystallization, etc., by Arnold Hague and J. P. Iddings. 1885. 8°. — pp. Price — cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Dr. C. A. White. 1885. 8°. — pp. 3 pl. Price — cents.

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. — pp. Price — cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. — pp. 1 pl. Price — cents.

21. The Lignite of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. — pp. 5 pl. Price — cents.

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STATISTICAL PAPERS.

A fourth series of publications having special reference to the mineral resources of the United States is contemplated.

Of that series the first has been published, viz:

Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

The second volume of this series, **Mineral Resources 1883 and 1884**, is in preparation and will soon be put to press.

Correspondence relating to the publications of the Survey, and all remittances, which must be by POSTAL NOTE or MONEY ORDER, should be addressed

TO THE DIRECTOR OF THE

UNITED STATES GEOLOGICAL SURVEY,

Washington, D. C.

WASHINGTON, D. C., *April 30, 1885,*

DEPARTMENT OF THE INTERIOR

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

T H E

ELECTRICAL AND MAGNETIC PROPERTIES

OF THE

IRON-CARBURETS

BY

CARL BARUS and VINCENT STROUHAL



WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

P R E F A C E .

Early in 1881 one of us submitted to Prof. G. F. Becker, geologist in charge of the Division of the Pacific, a brief digest of the facts showing the singular adaptability of the electrical properties of the iron-carburets for the classification of these products, with the request that permission be given us for the extension of the work in the laboratory of the Geological Survey. Professor Becker at once indorsed the project enthusiastically, and owing to his advocacy our proposal shortly after received the assent of the Hon. Clarence King, then Director of the Survey,—given with the proviso that the electrical researches be not prosecuted to such an extent as to occupy us exclusively.

Divers special investigations and routine duties, together with the labor involved in providing for the organization of a physical laboratory, prevented us from giving the furtherance of the proposed researches the attention necessary. Nevertheless, data of a varied character continually accumulated, while the scope and the conception of our general problem enlarged at an unexpectedly rapid rate. The publication of our results in some connected form, therefore, urged itself more and more seriously upon us.

About a year ago our plan was effectually encouraged by Prof. F. W. Clarke, chief chemist of the United States Geological Survey.

The experiments to be discussed in this memoir have occupied our available time during the last five years. Notices, more or less complete, have appeared abroad from time to time in places not readily accessible to the public. Some of the papers it was deemed necessary to publish in German with considerable fullness. But all English publication has been purposely delayed, not only because we desired to reduce the results originally expressed in terms of the German standards to the more current and now legal denominations of ohm, volt, etc.,¹ but principally because it seemed expedient for facility of comparison to refer all our data to the uniform temperature, zero centigrade. This

¹ In making this reduction the legal equation, 1 ohm = 1.06 S. U., was made use of in all chapters with the exception of III and IV, the results of which were reduced at an earlier date and when 1 ohm = 1.05 S. U. appeared to be nearer the truth. This, however, is of no serious significance, because in these chapters the relative values of resistance are alone of interest. The absolute accuracy of the reduced values is of course immediately dependent on the absolute accuracy of the German standards (Siemens) at our disposal.

premised an accurate knowledge of the relation between electrical conductivity and temperature for iron, for steel in different states of temper, and for cast iron, and required excessively tedious labor.

The results in Chapter I on the electrical temperature-coefficient of iron-carburets present an unexpected range of variation, and thus possess intrinsic interest.

In Chapter II we investigate and discuss the conditions of the operation of tempering. This chapter is fundamental. Such facts as essentially sustain the argument underlying the whole of the present work are, therefore, emphasized with a larger number of experimental data than would otherwise be necessary.

In Chapter III we attempt to throw new light on the laws set forth in Chapter II by following them into their ulterior consequences. With the aid of certain allied electrical properties of alloys and of malleable cast iron, the nature of the phenomenon of hardness as presented by steel is discussed from every available physical and chemical point of view, within the scope of the present purposes.

In Chapters IV, V, and VI, the method for the accurate definition of hardness, and the scheme of operations for tempering developed in Chapter II, are consistently applied to analogous magnetic phenomena. The nature of the dependence of magnetization on the three independent variables of cylindrical rods, viz: carburization, ratio of dimensions, hardness, for given conditions of structure, is carefully discussed and in part graphically represented. Rules are finally given for the treatment of magnets, such that exceptionally great retentiveness, both as regards the hurtful effects of temperature and time and of shocks, may be conveniently attained with the least available sacrifice of magnetization.

We may add that a supplementary Bulletin is now in preparation, in which the very remarkable annealing effect of high temperatures (400° . 1000°) will be magnetically discussed, and furthermore the degree of approximate coincidence between the physical state (of the necessarily linear rod) characterized by the unique maximum of magnetizability and the physical state of maximum density of steel, will be determined. That these states must be found very nearly coincident, our present results permit us to predict.

In Chapter VII, finally, we endeavor to generalize upon the foregoing results, as a whole; to restate the fundamental laws with greater accuracy and breadth of scope than was possible in the earlier chapters; and, finally, to deduce from all a method for the physical definition of iron-carburets.

Minor discussions, the relevancy of which does not justify their immediate introduction into the chapters proper, are frequently introduced as addenda.

We desire in this place particularly to emphasize that throughout the present work the terms "*thermo-electrically positive*" and "*thermo-electrically negative*" are to be understood in the way defined by the original

investigators, Seebeck,³ Becquerel,³ Hankel;⁴ *i. e.*, with reference to the series arranged thus:

— Bi.... Cu... Fe.... Sb +,

an acceptation which we believe to be general on the Continent.⁵ In England the above terms are received in a sense which is precisely the opposite of this; that is, with reference to the thermo-electric series,⁶ arranged thus:

+ Bi.... Cu... Fe.... Sb —.

Of the two methods of designation, the latter is obviously the more logical and consistent, as will readily be seen, for instance, if the galvanic and the thermo-element be analogously described. And if we refrained from embodying the latter acceptation in this memoir, we have done so merely because of the great liability to error encountered in changing the sense of every thermo-electric expression and diagram, as well as the signs of all of the many thermo-electric data. Isolated constructions are too apt to be overlooked, and this in a way completely to mar the drift of the context. But the English reader will find no difficulty in making this change of sign for himself in any set of thermo-electric data which may interest him. To avoid all misconception, moreover, we give the direction of current in each essential case.

Much of the work was done abroad in Professor F. Kohlrausch's laboratory. It is a pleasant duty which permits us to extend to Professor Kohlrausch, in this place, our grateful acknowledgments, not only for the kindly interest with which he regarded the progress of the experiments throughout their extent, but for much valuable advice by which the papers have materially profited.

We desire to mention, in conclusion, that work done by us conjointly, if published in German, is to be put under S. and B.; if in English, under B. and S., conformably with an original agreement.

C. BARUS.

V. STROUHAL.

PHYSICAL LABORATORY,

UNITED STATES GEOLOGICAL SURVEY,

Washington, December 1, 1884.

³Seebeck: *Gilb. Ann.*, LXXIII, pp. 115 and 430, 1823.

³Becquerel: *Ann. de Chim. et de Phys.*, XLI, p. 353, 1829.

⁴Hankel: *Pogg. Ann.*, LXII, p. 197, 1844.

⁵Cf. Wiedemann: *Lehre v. d. Elektricität*, II, p. 248 et seq., 1883. Mousson: *Physik*, III, p. 381 et seq., 1875. Jamin: *Cours de Physique*, 2d ed., T. III, p. 42, 1869.

⁶Cf. Jenkin: *Electricity and Magnetism*, p. 175 et seq., 1880. Maxwell: *Electricity and magnetism*, 2 ed., Vol. I, p. 338-9, 1881.

SUPPLEMENTAL.

The principal contents of the supplementary Bulletin referred to in the above preface may expediently be placed on record here:

1. The inter-dependence of density, electrical conductivity, maximum of permanent magnetization, maximum of permanent hardness of linear cylindrical steel rods, under all permissible conditions of temperature. The location of the unique magnetic maximum.

2. The bearing of temperature and time of exposure on the temperature-value of the color of the oxide-films.

3. The internal structure of tempered steel.

4. Certain synthetic methods of production of iron-carburets, available for the construction of the classification-diagram.

B. & S.

WASHINGTON, *March 27*, 1885.

(600)

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INTRODUCTION.

To avoid ambiguity and vagueness we will state here, at the outset, that the considerations presented in this memoir apply to that species of hardness which can be imparted to steel by a process of tempering; i. e., by a process of sudden cooling from a given temperature in red heat, accompanied by a stated amount of subsequent annealing. Such an operation, regarded as a method in virtue of which the metal acted upon experiences a particular and characteristic kind of strain, must be accompanied by a series of physical effects peculiar to itself. It is true that the conditions which determine the efficacy of tempering will themselves have to be accurately defined. Even under favorable circumstances these are not thoroughly within the observer's control, or, at best, are attainable with extreme difficulty. All results are, therefore, distorted by a variety of anomalies. But in the great number of data investigated a certain normal effect clearly appears, and it is to this that our remarks apply. In other words, we have been led in an unavoidably laborious way to the results of theoretically perfect tempering.

With regard to the hardness of steel, we cannot as yet rigidly discriminate between the effect to be ascribed to a change in the quality of carburization and that which is due to the strain simultaneously experienced; i. e., the numerical value of the importance of the said effects has as yet remained undeterminable, though much has been done toward assigning to each its respective limit. But, *a priori*, in so far as the character of this strain-effect will enable us satisfactorily to interpret a majority if not all of the attendant physical phenomena, we are temporarily justified in giving the mechanical postulate preference. At all events it is frequently permissible to abstract from the chemical change altogether, and to speak of tempering a rod to glass-hardness, just as we do of magnetizing it to saturation, for instance. Both operations may be said to be such that more of a given kind of strain (hardness in the one case and magnetism in the other) is originally imparted to the rod than it is able, *of itself*, to maintain. A part of this disappears, while a residue, characteristic of the nature of the rod and of the physical circumstances under which it exists, is permanently retained. This consideration suggests some analogies between hardness and magnetism. Irrespective of its practical importance and from a purely physical point of view, tempering possesses an intrinsic interest inferior only to magnetization, or indeed comparable with it. Of the enormous stress which the former operation enables us to apply, the steel rod, in virtue of a peculiar internal structure, retains a phenomenal amount. This great intensity of available strain we may cause to disappear as gradually

or to reappear as often as we please. Conformably with the change of mechanical state, the extreme values of the electrical and magnetic properties of steel comprehend a similarly extended interval. We are thus enabled to follow these, in the case of the same material, through a range of variation that is enormous, and must throw new light on their intrinsic nature.

Another point deserves brief mention here. If we conceive a theoretically perfect process of tempering to glass-hardness, and suppose it applied to rods identical in every respect, the results must necessarily be identical. In other words, the type of internal structure presented by the first would be reproduced in all subsequent rods. Take the comparatively simple but important case of cylindrical rods: The density of the elementary cylindrical shells, coaxial with the respective cylinders, would be the same for the same radius; the distribution of density along similar radii would follow the same law. If now the rods be identically annealed the results must still be identical, and thus we arrive eventually at identical soft states. It follows, therefore, that for rods of the same dimensions (*diameter*) and composition the magnetic properties are immediately comparable as functions of hardness.

This we are no longer at liberty to assume when the (cylindrical) rods otherwise identical, have different diameters. For this reason alone the rods, though tempered alike, *i. e.*, subjected to the same operation, are to be regarded as structurally dissimilar. It is in place here to present some concise meaning for the term "structure" as applied to hard steel rods. We, therefore, define it as the law of the variation of density encountered on a passage along any radius of a given (cylindrical) steel rod from its axis to its circumference. This premised, it is not absolutely impossible (however improbable) that rods of different diameters, identically tempered, may, *cæteris paribus*, show identical structures. That such a unique condition of things cannot be postulated is obvious at once. Indeed, the manner of variation of the law of distribution of density, as we pass from rods of a given thickness to rods of any other thickness, is not even conjecturable, and we cannot, therefore, consistently compare the magnetic intensities of rods of different diameters as functions of hardness. In the most favorable case we would encounter in our passage from rod to rod, besides the difference of hardness, something of the nature of a change of parameter, expressing the necessary difference of internal structure referred to. In other words, it will be shown in the sequel that with a given thickness, a characteristic family of magnetic curves may be obtained, referred to hardness and length of rod as independent variables. We infer that such a family exists for each thickness, and that our passage from one given diameter to another is expressible by a difference in the value of a parametric constant.

We have mentioned magnetic phenomena in particular, because it is here that the evidence derived from data illustrating the influence of structure is singularly cogent.

THE ELECTRICAL AND MAGNETIC PROPERTIES OF THE IRON-CARBURETS.

By CARL BARUS and VINCENT STROUHAL.

CHAPTER I.

ON THE RELATION BETWEEN ELECTRICAL CONDUCTIVITY AND TEMPERATURE IN THE CASE OF STEEL IN DIFFERENT STATES OF HARDNESS, OF WROUGHT IRON, AND OF CAST IRON.

STEEL.

Earlier results.—The experiments made thus far on the resistance-effect of temperature⁷ scarcely permit us to distinguish in this particular between iron and steel. In fact, the data in hand for the said coefficients lie within about the same interval, 0.004 to 0.005, both for the one metal and the other. We will give as examples some of the best results of earlier observers.

According to Mousson,⁸ the electrical resistance s_t at the temperature t is expressible in terms of s_0 , the corresponding quantity at zero, by an equation with a single constant:

$$s_t = s_0 (1 + 0.00421 \times t)$$

for iron;

$$s_t = s_0 (1 + 0.00406 \times t) \text{ to } s_t = s_0 (1 + 0.00424 \times t)$$

for steel.

Benoit,⁹ who carried his researches to much higher degrees and through much greater intervals of temperature, finds:

$$s_t = s_0 (1 + 0.00452 \cdot t + 0.000\ 005\ 83 \cdot t^2)$$

in case of iron;

$$s_t = (1 + 0.00498 \cdot t + 0.000\ 007\ 35 \cdot t^2)$$

in case of soft steel.

Nevertheless we felt justified in believing that these researches in case of a substance which, like steel, is capable of existing in so many enormously different states of hardness, which presents such an incomparably wide range of values of electrical conductivity, are far from complete; we regarded the assertion warrantable that steel cannot, under all circumstances, possess a temperature-coefficient of electrical resistance so little different from that of iron. Indeed, we had reasons to

⁷For a very complete digest of the experimental results in question, see G. Wiedemann, *Lehre von der Elektrizität*, I, p. 502-510, 1882.

⁸Mousson: G. Wiedemann, I. c., p. 507.

⁹Benoit: *Comptes. Rend.*, LXXVI, p. 342, 1873. Carl's Rep., IX, p. 55, 1873.

presume that between the resistance of a metal in any given physical state and the corresponding temperature-coefficient, a relation would in all probability be discoverable, and that an example of such a relation could be most satisfactorily studied with steel itself.

Analogous behavior of alloys.—Some facts lending favor to this view may be cited. It is known that alloys of two metals vary in marked degree as regards their electrical conductivity with the relative quantity of a second or foreign metallic ingredient added to the original metal. Great numbers of valuable results on these relations have been gathered by Matthiessen and Vogt.¹⁰ Thus, for instance, the alloy silver-platinum, according to these observers, shows the following electrical behavior; If λ_t be the (relative) electrical conductivity of a given silver-platinum alloy at t° ; if volume-percents of platinum alloyed to silver be understood; and if the wires be supposed hard drawn; then,

Platinum, 0 per cent. $\lambda_t = 100 - 0.38287 \cdot t + 0.000\ 984\ 8 \cdot t^2$;

Platinum, 2.51 per cent. $\lambda_t = 31.640 - 0.03936 \cdot t + 0.000\ 036\ 42 \cdot t^2$;

Platinum, 5.05 per cent. $\lambda_t = 18.031 - 0.01395 \cdot t + 0.000\ 011\ 82 \cdot t^2$;

Platinum, 19.65 per cent. $\lambda_t = 6.696 - 0.00221 \cdot t + 0.000\ 001\ 393 \cdot t^2$.

If we have reference to a small interval of temperature only, these results may be more perspicuously given by the aid of a single (mean) coefficient calculated from the observed conductivities. More simply, therefore,

Platinum, 0 per cent. $\lambda_t = 100 (1 - 0.00383 \cdot t)$;

Platinum, 2.5 per cent. $\lambda_t = 31.6 (1 - 0.00124 \cdot t)$;

Platinum, 5.1 per cent. $\lambda_t = 18.0 (1 - 0.00077 \cdot t)$;

Platinum, 19.7 per cent. $\lambda_t = 6.7 (1 - 0.00033 \cdot t)$.

Herefrom it is obvious that the temperature-coefficient of an alloy varies continuously and in a pronounced way with its electrical con-

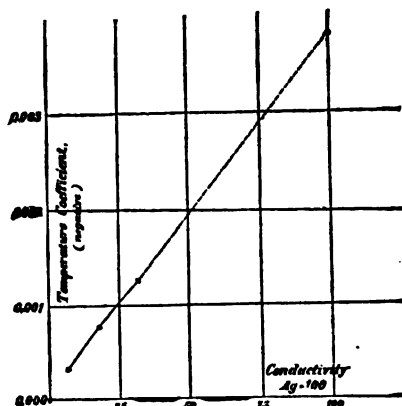


FIG. 1.—Electrical conductivity and temperature-coefficient of silver-platinum alloys.

ductivity. This becomes all the more strikingly apparent when the results are represented graphically.

¹⁰Matthiessen and Vogt: Pogg. Ann., CXXII, p. 19, 1864.

Similar results, but less complete, and therefore superfluous here, we ourselves obtained with German silver. But, to give an instance: the specific resistance, s , of the German silver wire of C. Vogel, Berlin, was found to be (s , given in cm/cm^2 , microhm),

$$s_i = 16.4 (1 + 0.00064 \cdot t),$$

whereas for that of W. Siemens, Berlin,

$$s_i = 39.0 (1 + 0.0009 \cdot t).$$

Now we shall show elsewhere that the analogy between the electrical behavior of steel in different states of hardness, and that of alloys of two metals in different proportions is, from certain points of view, very complete. It follows, therefore, that a relation similar to the one set forth is to be anticipated in case of steel, such that the variation of electrical resistance produced by tempering must be accompanied by a similarly continuous but inverse change of the values of the temperature-coefficient of steel. Our experiments fully corroborate this.

Resistance-temperature equation.—Before proceeding further, however, we may remark that it would be impossible in case of steel to adhere to the very desirable formula

$$s_i = s (1 + at + bt^2),$$

throughout. Consistency, therefore, induces us to assume a linear relation in all cases. The reasons are these: the relation between resistance and temperature-coefficient to be investigated necessarily and primarily excludes all possibility of permanent change in the material itself. When glass-hard steel is examined, the interval of temperature within which the rod may be heated or cooled without experiencing perceptible annealing is very limited. The same is true of moderately annealed steel. We are as yet ignorant of the effects of this kind which may possibly also be produced by cooling below zero. Hence it is indispensably necessary to vary the temperature of glass-hard rods only so much as is just called for, if the measurements are to furnish satisfactorily reliable data. Should an annealing effect occur, the results would not of course be comparable. Now the available interval of temperature is fully large enough for the linear formula. It is insufficiently so in the other case; for in the quadratic formula it is possible to change the coefficient of t to quite an appreciable extent without producing marked variation in the values of s_i , if only an appropriate and compensatory change be made in the coefficient of t^2 , simultaneously. Hence the simple formula

$$s_i = s_0 (1 + \alpha t)$$

has been made use of throughout, where t was permitted to vary within the interval 10° to 35° only.

Method of measurement.—The changes of temperature, and therefore also those of resistance, being very slight, amounting only to a few hundredths ohm, it was necessary to make the electrical measurements with extreme accuracy. For this purpose the method of Matthiessen and Hockin, which we have repeatedly used, proved to be admirably

serviceable. A few modifications had to be introduced. In the place of the two needles originally employed for obtaining contacts at fixed distances apart, and which if submerged in water would have introduced the disturbing effects of loose contacts, two fine copper wires were tightly wound around the extreme parts of the steel rod under experiment, and fastened in a way that made sliding impossible. The rod was then alternately placed in two vessels containing cold and warm water respectively, care being taken not in any way to strain the copper circuit wires. The short-circuiting through distilled water from one fine copper wire to the other is obviously negligible.

The temperature of the cold bath was approximately that of the room, and very constant; that of the warm bath varied during a single measurement not more than a few tenths of a degree. Temperature being read before and after the resistance measurement, the mean value could be regarded as a very satisfactory datum. The steel rod examined was placed first in the cold, then in the warm, and finally again in the cold bath. The mean of the measurements 1 and 3 was therefore to be combined with 2, 4 and 6 with 5, etc. The degree of approximate equality of the results of these distinct sets of observations, and the agreement between the measurements 1, 3, 4, 6, etc., give a good estimate of the accuracy of the work.

Material. Resistance-value of oxide-tints.—The material used was that employed in all our researches, English "silver" steel in rods 0.15 cm. in diameter. After having been suddenly chilled in great numbers, certain of them were annealed by the electrical current, in this way: Having carefully polished the hard rod, it was introduced into the circuit of a dynamo-electric machine. As the temperature of the wire increased the oxide-tints appeared in a strikingly perfect manner, and it was only necessary to regulate the current cautiously and stop the operation at a given moment to obtain any oxide-tint desired almost uniformly over the whole length of the wire. The observations of this paragraph therefore give in an approximate way the temper-value of the oxide-tint appearing in air on a bright hard steel rod, in terms of electrical resistance.

Results.—The following table, 1, contains a perspicuous comparison of the data of observation as obtained with six steel rods in different states of temper. For the diameter 2ρ (cm) of the rod and the length l (cm) direct measurement showed the resistance w (ohm) at the temperature $t^\circ (C.)$. Also the resistance W (ohm) at T° . This is sufficient for the calculation of w_0 for 0° and α , the required coefficient. The known dimensions then enable us to deduce the specific resistance s (cm/cm² 0°). Finally, we give the specific gravity Δ of the wires, calculated for the known dimensions and the known weight. Our object in computing this constant was primarily that of checking the values for the sections of our rods as measured by the aid of the microscope. But they furnish a satisfactory corroboration of the general increase of dens-

ity of steel on passing from the hard to the soft state, conformably with the results of C. Fromme:

TABLE 1.—*Temperature-coefficient of steel.*

Rod.	$2 \rho, l, \Delta$	w	t	W	T	w_0	α	s
	cm.	ohm.		ohm.		ohm.		microhm.
Glasshard	$2 \rho = 0.151$	0.04528	10.0	0.04685	32.9	0.04450	0.00161	45.7
	$l = 17.52$	20	10.2	59	29.5		160	
	$\Delta = 7.56$	24	10.4					
Annealed light-yellow	$2 \rho = 0.148$	0.03107	10.2	0.03297	35.5	0.03030	0.00250	28.9
	$l = 17.98$	06	10.3	65	32.2		268	
	$\Delta = 7.57$	10	10.6					
Annealed yellow	$2 \rho = 0.150$	0.02782	10.9	0.02950	38.2	0.02696	0.00278	26.3
	$l = 18.17$	84	11.0	22	29.6		279	
	$\Delta = 7.54$	81	11.0					
Annealed blue	$2 \rho = 0.149$	0.02043	10.0	0.02191	32.5	0.01978	0.00327	20.5
	$l = 18.77$	47	10.1	75	28.8		352	
	$\Delta = 7.56$	45	10.2					
Annealed light-blue	$2 \rho = 0.148$	0.01948	9.8	0.02097	31.6	0.01881	0.00357	18.4
	$l = 17.58$	46	9.5	70	27.7		363	
	$\Delta = 7.66$	47	9.7					
Soft	$2 \rho = 0.146$	0.01690	9.7	0.01850	32.5	0.01625	0.00428	15.9
	$l = 17.13$	94	9.9	27	29.4		419	
	$\Delta = 7.69$	96	10.0					

If for α we take mean values, and compare these with the degrees of hardness of steel, characterized by s , we obtain more clearly:

TABLE 2.—*Oxide-tint, specific electrical resistance and electrical temperature-coefficient of steel.*

	$s \frac{\text{cm}}{\text{cm}^2} 0^\circ$	α
Glasshard	45.7	0.00161
Annealed light yellow	28.9	244
Annealed yellow	26.3	280
Annealed blue	20.5	330
Annealed light blue	18.4	360
Soft	15.9	423

The electrical temperature-coefficient of steel, therefore, decreases in proportion as its specific resistance or its degree of hardness increases, at a rate diminishing as we pass from soft to hard steel.

The following little table interpolated from the above values, for practical purposes, may be put on record here:

TABLE 3.—*Specific electrical resistance and electrical temperature-coefficient of steel. Practical table.*

s	α	s	α	s	α	s	α
$\frac{\text{cm}}{\text{cm}^2} 0^\circ$		$\frac{\text{cm}}{\text{cm}^2} 0^\circ$		$\frac{\text{cm}}{\text{cm}^2} 0^\circ$		$\frac{\text{cm}}{\text{cm}^2} 0^\circ$	
microhm.		microhm.		microhm.		microhm.	
10	0.0050	21	0.0033	32	0.0022	43	0.0017
11	43	22		33		44	17
12	46	23	31	34	21	45	16
13	44	24	29	35	21	46	16
14	42	25	28	36	20	47	15
15	41	26	27	37	19	48	15
16	39	27	27	38	19	49	15
17	38	28	26	39	19	50	15
18	36	29	25	40	18	60	13
19	35	30	24	41	18	70	13
20	34	31	23	42	17	80	12

WROUGHT IRON.

Digest of earlier results.—The relation between electrical resistance and temperature in case of iron has been studied by a large number of observers, among whom Lenz, Becquerel, Arndtsen, Mousson, and others, are to be mentioned. But the most comprehensive and accurate data are unquestionably those given by Matthiessen and Vogt.¹¹ These will therefore be discussed here.

Matthiessen and Vogt assume the quadratic formula

$$\lambda = \lambda_0 - at + bt^2$$

for λ , the conductivity of any given metal, relatively to hard-drawn silver ($\lambda_0=100$). Their results for a and b , in case of fifteen samples of iron, conveniently abbreviated, are contained in Table 4.

TABLE 4.—*Electrical temperature-coefficient and electrical conductivity of divers samples of iron.*

Description of sample.	No.	a	b	λ_0
Electrotype iron; Nos. 2 and 4 ignited in hydrogen and in air, respectively	1	0.512	0.00129	(16.810) ¹²
	2	0.519		134 (16.810) ¹²
	3	0.514		132 (16.810) ¹²
	4	0.509		127 (16.810) ¹²
	5	0.473		112 15.712
Drawn iron wire, analyzed chemically	6	0.472	112	15.640
	7	0.440	102	14.204
	8	0.453	112	12.132
	9	0.463	106	11.723
	10	0.418	092	10.606
Iron wires of different degrees of carburation	11	0.404	092	9.921
	12	0.397	091	9.449
Piano-forte wire	13	0.425	092	12.293
Watchspring	14	0.340	068	8.568
Commercial iron wire	15	0.428	090	18.774

For the sake of facilitating a comparison of these results with our own, we reduced them, as nearly as possible, to absolute values of $s \frac{\text{cm}}{\text{cm}^2} 0^\circ$ microhm, by accepting for "silver hard," for which Matthiessen and Vogt put $\lambda=100$,

$$s=1.574.$$

Moreover, the values have been arranged, commencing with pure iron, in the order of the values for resistance, the coefficient of quadratic t being discarded and only linear a introduced. The interpretation to be given to " α interpolated" will be explained presently.

¹¹ Matthiessen and Vogt: Pogg. Ann., CXVIII, p. 431, 1863.

¹² Probable value for pure iron, hard, deduced from the observations with impure metal, from an inspection of the respective temperature-coefficients,

TABLE 5.—*Specific electrical resistance and electrical temperature-coefficient of different kinds of iron.*

Description of sample.	$s \frac{\text{cm}}{\text{cm}^2} \text{ } ^\circ\text{C}$	α observed.	α interpolated.
	<i>microhm.</i>		
Nos. 1 to 4	9.4	0.0052	0.0052
No. 5	10.0	47	50
No. 6	10.1	47	50
No. 9	10.7	46	49
No. 7	11.1	45	48
No. 15	11.4	43	47
No. 12	11.8	42	46
No. 8	13.0	45	44
No. 10	14.8	42	41
No. 11	15.9	40	40
No. 12	16.7	40	37
No. 14	18.4	34	36
Steel, soft	15.0	43	40

Resistance-temperature equations of iron and of steel.—The first line of these data, showing the mean value of a number of observations with pure iron, is the most reliable. If this be added to our results for steel (Table 2), the whole series of results may be compared graphically, by representing specific resistance, s , as abscissa temperature-coefficient, α , as ordinate. The points lie satisfactorily on a locus of definite character, which in its turn may be utilized for purposes of interpolation. In this way the last column of the foregoing table (" α interpolated") has been deduced, the temperature-coefficient for each value of specific resistance for the sample of iron cited being selected. The discrepancies or differences between observed and calculated results are not larger than a combination of observations made on the great variety of material by different observers, together with the wide range of possible errors incident to all, would lead us to anticipate. Even the position of soft steel with reference to the curve is, in every respect, satisfactory. It is in this way, finally, that the practical results in Table 3 were derived.

Benoit¹² finds the following relations between resistance and temperature for soft iron and soft steel, respectively:

$$s_i = 0.1272 (1 + 0.00452 \cdot t + 0.0000058 \cdot t^2),$$

and

$$s_s = 0.1149 (1 + 0.00498 \cdot t + 0.0000074 \cdot t^2),$$

$$(Hg = 1 \text{ m } | \text{ mm}^2).$$

These results referred to microhms and cm/cm^2 are

$$s = 12.1 \quad \alpha = 0.00452$$

for iron, and

$$s = 10.9 \quad \alpha = 0.00498$$

for steel. Both sets of values are in good accordance with our graphic representation. We obtain by means of this:

$$\text{For } s = 12.1, \text{ the value } \alpha = 0.00457,$$

and

$$\text{For } s = 10.9, \text{ the value } \alpha = 0.00485.$$

¹² Benoit: Comptes rend., LXXVI, p. 342, 1873. Wiedemann, l. c., p. 525. The small value $s = 10.9$ obtained by Benoit for soft steel is remarkable and exceptional.

CAST-IRON.

Anticipative results.—Of particular interest in connection with this discussion is the behavior of the most highly carburized of commercial iron-products, cast-iron. Observations for pairs of the electrical magnitudes under consideration, for this material, are not in hand. Elsewhere we will describe certain experiments, made in some number, with reference to the thermo-electric and galvanic properties of cast-iron. Here we need only mention, that the specific resistance of this metal is very decidedly larger than the largest attainable results for glass-hard steel. If, therefore, a relation¹⁴ between electrical conductivity and electrical temperature-coefficient of the kind premised, actually exists, then this latter quantity must, in like manner, be smaller than the smallest results arrived at in case of steel.

* To test this inference, three samples were selected from our supply of cast-iron rods, Nos. 13, 14, 15, each about 25 cm. in length, and their resistance in the soft or thoroughly annealed state (annealed at red heat and cooled very slowly) determined at different convenient temperatures. But this resistance, in view of the comparatively large section of the said rods (about 0.4 cm²) being as small as 0.004 ohms, the measurement had to be made even with greater precaution than was necessary in the case of steel.

Method of measurement.—The method of measurement was, however, essentially identical in the two sets of experiments, being Matthiessen and Hockin's. The terminal wires of copper, wherever necessary insulated by glass tubes, were wrapped around and soldered to the cast-iron rods; these, together with the insulated terminals and a good thermometer, introduced into a wide glass tube. Through the latter, closed at both ends by suitably perforated corks, securing tubes of influx and efflux, vapor at the boiling point of the respective liquids continually circulated. Methyl alcohol vapor, and steam were especially convenient. The tube itself, thickly jacketed with felt and cloth, showed a desirably constant temperature throughout the course of the work. All these precautions were necessary, for the ulterior reason of excluding possible thermo-electric action at the junctions of cast-iron and copper. Such currents are otherwise readily evoked in intensity sufficient utterly to vitiate the accuracy of the measurements.

Results.—The following table will show that the experiments conducted with this care were satisfactorily successful. Here *a* and *b* denote the sides of the approximately rectangular section of the cast-iron rods; *l*, the effective length in the resistance measurements. From an inspection of the resulting errors, the linear relation assumed to exist

¹⁴A detailed discussion regarding the electrical effects of the strain accompanying hardness and of carburization, respectively, will be given in Chapter III.

between resistance and temperature within the interval 0° — 100° , will be found to be acceptable.

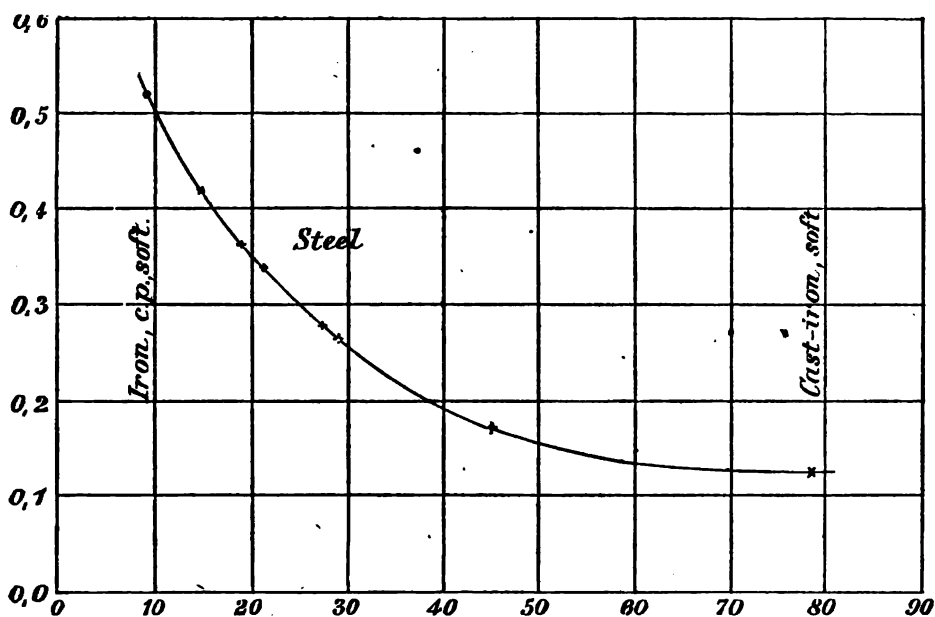


FIG. 2.—Diagram of the relation between specific electrical resistance and temperature-coefficient for wrought iron, for steel, and for cast iron.

The results show that the mean temperature-coefficient of cast iron falls very fairly on what may be considered a prolongation of the locus obtained for iron and steel (see figure), or that the electrical temperature-coefficients of iron-carburets, in general, may be regarded as a definite function of the respective specific resistances:

TABLE 6.—Temperature-coefficient of cast-iron.

Rod No.	Constants.	t	w	t mean.	w observed.	w calculated.	Diff.	α	α	α
	cm.	$^{\circ}C$.	ohm.					ohm.		microhm.
13	$a = 0.640$ $b = 0.656$ $t = 20.10$	23.8	0.003749	23.5	0.003743	0.003743	0	0.008637	0.00124	76.0
		23.2	3738							
		67.2	3938	67.3	3941	3941	0			
		67.5	3943							
		99.4	4093	99.3	4085	4085	0			
		99.3	4077							
14	$a = 0.643$ $b = 0.642$ $t = 20.10$	22.8	3839	22.8	3837	3829	8	3712	138	76.2
		22.8	3835							
		67.8	4041	66.5	4051	4068	-17			
		71.2	4061							
		99.5	4235	99.5	4235	4224	11			
		99.5	4235							
15	$a = 0.646$ $b = 0.647$ $t = 20.10$	28.0	4095	18.7	4090	4102	-3	4008	126	83.3
		17.8	4095							
		18.3	4108							
		66.0	4347	66.0	4347	4311	6			
		66.0	4347							
		100.0	4500	100.0	4509	4512	-4			
		100.0	4490							
		100.0	4536							

DEDUCTIONS.

Analogous behavior of alloys and of iron-carburets.—The data contained in the above tables throw some light on the probability of an analogy between alloys generally and iron carburets, inasmuch as they show a certain similarity of behavior in both kinds of products. It is not impossible that we have here in hand examples of a general law; in other words, it may be plausibly argued that whenever the properties of a primary metal are altered by addition of various quantities of a second substance (metallic or non-metallic) alloyed thereto, that then the known variation of electrical resistance is invariably accompanied by a corresponding variation of the electrical temperature-coefficient—in such a way that an increment of the former corresponds to a decrement of the latter in accordance with some fundamental relation. In the case of ordinary alloys, small quantities of a second metal are alloyed to the original material, producing the known electrical effect. In the case of steel the process of tempering is the cause of a change in the quality of carburization, so that in a highly tempered bar more *combined* or electrically active carbon is, as it were, alloyed to iron than in one of inferior temper or in a soft rod. Hence the corresponding electrical effect. But it is well to waive this subject here to discuss it more satisfactorily in another chapter.

Temperature-coefficient and volume.—We shall show elsewhere¹⁵ that for steel at least, and possibly for all non-electrolyzed conductors, the specific resistance may, with some fitness, be regarded as a volume-function only. Probably a similar remark may also be made with reference to the temperature-coefficient of steel, and it would appear that with this metal, the most promising of the available means for the study of the bearing of specific volume on specific resistance and temperature-coefficient, is furnished us. Clausius¹⁶ was the first to call attention to the approximate proportionality of the resistance of most pure metals with their absolute temperatures. If we accept Mathiessen's general relation between resistance and temperature for pure metals:

$$s_t = s_0 (1 + at + ct^2), \quad a = 0.003824, \quad c = 0.000\,001\,26$$

and put

$$\frac{ds}{dt} = \frac{1}{273},$$

we find that at about 60° C. the said proportionality is accurate. There would be some propriety, therefore, in considering this state of the metals in question as a normal state, and the corresponding specific

¹⁵ Chapter III.

¹⁶ Clausius: Pogg. Ann., CIV, p. 650, 1858. Auerbach (Wied. Ann., VIII, p. 479, 1879) has endeavored to explain this circumstance, and also to interpret the exceptional value encountered in case of iron.

resistance as their normal resistance. It may be remarked, in passing, that the temperature to which *soft* steel must be cooled in order (theoretically) to annul its resistance coincides very nearly with the absolute zero of temperature.

ADDENDUM.

STATEMENT OF A RESISTANCE METHOD FOR THE MEASUREMENT OF HEAT-CONDUCTIVITY.

The success of the above application of Matthiessen and Hockin's method for the accurate measurement of very small increments of resistance, has suggested to us the availability of the same method in determining the necessary data for the calculation of heat-conductivity.

The subject of heat-conductivity has of late been largely discussed, especially in German literature. In most of the cases new methods have been proposed and employed. Our object herewith is to offer an experimental modification of the well-known method due to Biot, but first applied by Depretz,¹⁷ which we believe has certain practical advantages.

Depretz heats the ends of a straight rod of uniform section to different constant temperatures T and t ($T > t$). After the stationary thermal condition has set in, t_1, t_2, t_3 , the temperature of any three consecutive right sections, at the same distance l apart, respectively, are related as follows:

$$e^{\mu l} + e^{-\mu l} = (t_1 + t_3) : t_2 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where, moreover, μ for rods of the same section and of the same external conductivity is, under the assumption of constant l , inversely proportional to the square root of heat-conductivity. Suppose, however, that instead of measuring the temperatures at three consecutive equidistant sections, we propose to determine the resistances of three consecutive equal lengths l of the rod, after the thermal condition has become stationary. We have

$$dr = \frac{s}{q}(1 + \alpha t) dx,$$

where dr is the elementary resistance corresponding to the length dx , at the temperature t , s the specific resistance of the material, q its (uniform) section, α a given constant. In view of the steady thermal flow, we may write

$$dr = \frac{s}{q}[1 + \alpha(Ce^{\mu x} + C'e^{-\mu x})] dr.$$

If this equation is integrated successively between the limits l_2 and l_1 , l_3 and l_2 , l_4 and l_3 , where $l_4 - l_1 = l_3 - l_2 = l_4 - l_3 = l$, we obtain three equa-

¹⁷ Depretz: Ann. d. chim. XXXVI, p. 422, 1827; Cf. Langberg, Pogg. Ann., LXVI, p. 1, 1845; Wiedemann and Franz, Pogg. Ann., LXXXIX, p. 497, 1853.

tions from which the constants C and C^1 may be eliminated. The following relation results:

$$2n = e^{\mu l} + e^{-\mu l} = \frac{\frac{r_{31}}{r_o} - 1 + \frac{r_{43}}{r_o} - 1}{\frac{r_{32}}{r_o} - 1} \dots \dots \dots (2)$$

where r_o is the resistance of the length l , at zero. Equation (2) might have been more elegantly derived indirectly from equation (1) above.

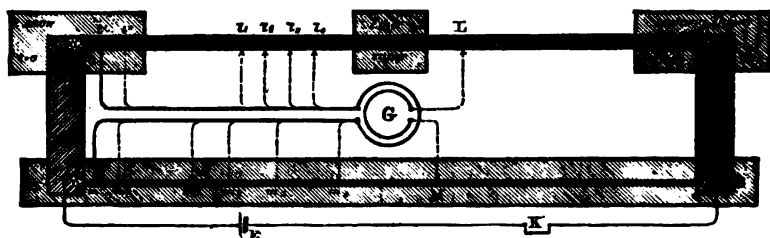


FIG. 3.—Diagram of a resistance-apparatus for measuring heat conductivity.

Suppose, now, that in connection with this result we use Hockin and Matthiessen's device of two corresponding sliding contacts in the manner indicated in the annexed diagram. Let

$$l'' - l' = l_2 - l_1 = l_3 - l_2 = l_4 - l_3 = l$$

Let the points $m', m'', m_1, \dots, m_4$ on the wire δe correspond to $l', l'', l_1, \dots, l_4$ in such a way that, if connection be made between any two of them with the prolonged terminals of a galvanoscope G , the needle of the latter will receive no additional impulse on momentarily closing the key K . Then we may write

$$2n = \frac{\frac{m_2 - m_1}{m'' - m'} - 1 + \frac{m_4 - m_3}{m'' - m'} - 1}{\frac{m_2 - m_1}{m'' - m'} - 1} ;$$

whence it follows that Depretz' method by application of Hockin and Matthiessen's device may be theoretically reduced to a simple *measurement of lengths*.

It is not our object here to go into any practical details.¹⁸ But we may remark that hurtful thermo-currents may be reduced to a minimum by using a sliding contact at the points l of a material thermo-electrically similar to the rod to be examined. Their effect would be that of changing the position of equilibrium of the needle of the galvanoscope, and they would not seriously influence the impulse given to it by momentarily closing K . Moreover, the ends, L and M , of an independent, permanently closed bridge-wire may be so adjusted as to compensate the thermo-electric disturbance entirely (end L), and

¹⁸The compendious form of Wheatstone's Bridge, invented by Kohlrausch, suggests itself for these measurements.

yet not interfere with the measurement (end M). In this case it is not necessary to close l' . . . l_4 for a short time prior to closing K , but both may be closed momentarily, the latter contact a little before and a little after the particular one of the former, with reference to which the observation is made.

It is our intention to endeavor to apply a procedure of this kind for the purpose of investigating whether the abnormal diminution of electrical conductivity due to tempering (about 70 per cent.) is accompanied by a corresponding variation of heat-conductivity. The plan would be the same as that detailed elsewhere.¹⁹

¹⁹Strouhal and Barus, Wied. Ann., XI, p. 976, 1880; *ibid.*, pp. 953-4, 977.

CHAPTER II.

ON THE CONDITIONS WHICH IN THE CASE OF STEEL ESSENTIALLY DETERMINE THE EFFICACY OF THE OPERATION OF TEMPERING; THE MEASUREMENT OF THE STATE OF HARDNESS OF STEEL.

INTRODUCTORY REMARKS.

Origin of the work.—At the outset of the present series of experiments it was our object to subject the relation existing between the amount of magnetization which saturated steel rods can permanently retain, and their mechanical condition, particularly their state of hardness, to a new and rigid investigation. We were led to this undertaking by the results shown in a paper by Barus,²⁰ in which it appears that the electrical properties of steel—its thermo-electric power and specific resistance primarily—furnish a datum of singular sensitiveness for the hardness of this material. It therefore lay within our scope and purpose to invent a method for obtaining as many well-defined degrees of hardness between the glass hard or suddenly chilled state on the one hand, and the soft or thoroughly annealed state on the other, as would be practicable.

During the progress of the work, however, the phenomena attending the operation of tempering, as exhibited by the thermo-electric power and the specific resistances of the different stages of hardness of steel, began more and more to engross us, and eventually became of sufficient importance to occupy our attention wholly. Thus it was that a special research, though partaking of the nature of a digression and calling for a larger expenditure of time than had been allotted to this part of the projected series of experiments, became almost necessary. The data in hand throw new light on the conditions determining the temper of steel, and indeed enable us to discuss the whole subject perspicuously and from a general standpoint. These remarks will suffice to account for the origin, purpose, and disposition of the parts of the present chapter.

Material used.—The steel used in this work was of the kind known as "English silver-steel."²¹ It came to our hands in the shape of rods, about 30 cm. long, varying in diameter between 0.03 cm. and 0.01 cm., drawn accurately cylindrical for the use of watchmakers. The rods were nominally identical in composition, and obtained from Cooks' Brothers, of Sheffield and Manchester. In view of the great complexity

²⁰ Barus, Phil. Mag. (5), VIII, pp. 341-68, 1879; Wied. Ann., VII, p. 338, 1879. Cf. Appendix to this Bulletin, p. 203.

²¹ See Chapter VII.

and vagueness associated with the term steel, it appeared necessary to confine the operations to the given type of this material—an exceptionally favorable type, moreover, when considered with reference to the enormous interval of hardness comprehended between its glass-hard and soft states. Chemical analysis of this individual member of the infinite family of possible steels would have been more than useless, as will clearly appear from a perusal of the present series of papers as a whole. As a rule we draw our inferences from rods broken from a single longitudinally homogeneous sample only. The purely physical relation sought is thus investigated unaffected by secondary phenomena or distortions, while the material, as it were, is represented by a series of temporarily constant parameters. In the present chapter this method of research is suggested naturally by the experiments themselves, and satisfactory material is easily obtained. But in the later chapters on magnetism, where the necessity of using chemically and structurally identical rods is much more urgent, these essential conditions are often secured only with difficulty.

APPARATUS FOR IMPARTING GLASS-HARDNESS TO STEEL.

In view of the great number of steel wires to be tempered, the construction of an apparatus by the aid of which the operation of sudden cooling could be expeditiously and conveniently carried out, and which would impart to the wires a uniformity of hardness throughout their length, was an essential requisite. The following machine answered the purpose satisfactorily:

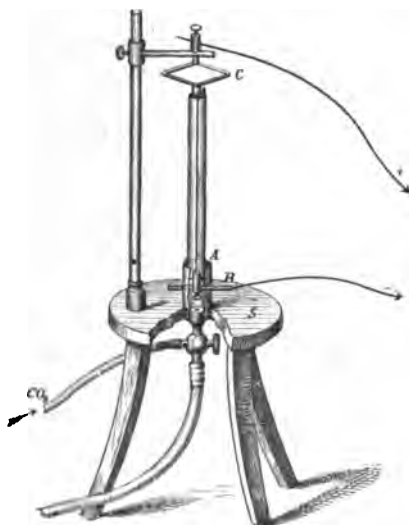


FIG. 4.—Apparatus for hardening steel rods.

In figure 4, *A* is a hollow cylinder 9 cm. long, of dense (box) wood, provided with a circular groove and slot so as to admit of its being securely fastened by a sort of bayonet-joint to a substantial tripod, or again removed, conveniently. Into the lower and wider part (3.0 cm. in diameter) of the aperture a closely-fitting faucet communicating with the water-mains by means of a hose, is inserted; into the upper opening of the same (1.5 cm. in diameter) there is fitted a glass tube of thin material and about 30 cm. long. This serves primarily as a protecting envelope for the steel wire stretched in its axis. Besides this gradually tapering canal, the box-wood cylinder is provided with a second perforation at right angles to the axis of the latter, in which a thick steel rod *B* (0.5 cm. in diameter) fits snugly.

The wire to be hardened is drawn tensely between two clamp-screws, in connection with the terminals of a powerful battery, in the following way: The lower clamp-screw possesses a longitudinal and a cross perforation. One end of the wire is fastened in the first of these holes by a lateral screw and then introduced into the wooden cylinder and attached glass tube, *A*, from below, whereupon the steel rod *B*, passed through the cross perforations in both cylinder and clamp-screw, and fastened by the vertical screw of the latter, puts the lower end of the wire in connection with one pole of the battery. As *B* may be rotated around its own axis and at the same time moved laterally, the wire may be satisfactorily centered. *A*, thus adjusted, is now attached to the tripod as above described, the faucet forced tightly in from below, and the upper end of the steel wire, which projects slightly out of the glass tube, grasped by a second clamp-screw. The latter forms a part of a peculiar spring *C*, in shape of a rhombus of very large horizontal but very short vertical diagonal. In this way a gentle tension, not so strong as to rupture the wire when red hot is constantly maintained, while the parts of the spring are thick enough to allow the passage of an intense galvanic current without becoming perceptibly heated. We have found that a wire symmetrically chilled and held tense in this way remains straight after the glass-hard temper has been imparted to it—an important desideratum. In order to centrally adjust the upper end of the wire, or to regulate the tension of the spring, the latter may be moved around and along a horizontal arm, which in its turn is similarly adjustable around a vertical post screwed to the tripod. To *C* and *B* the terminals of a powerful battery are suitably attached.

A current of dry carbonic acid gas continually circulating through the tube practically obviates the annoyance of oxidation during the heating to redness. To introduce this gas, the faucet is doubly perforated in the way devised by Senguerd. The larger of the canals is intended for the influx of water, the smaller for carbonic acid, and they are so disposed relatively to each other that if the one is open the other is necessarily closed. To manipulate the apparatus satisfactorily a considerable head of water is desirable. But even when these facilities are available,

the water, on opening the faucet, is apt to enter the tube with a squirt, chilling some parts of the wire before the main column advances, and in this way vitiating the otherwise attainable uniformity of glass-hardness. For this reason a second faucet (not shown in the figure) belonging to the hydrant was put into use. We operated in this way: The former faucet was first opened, producing no other effect than the interruption of the current of carbonic acid. Then one of us rapidly opened the second faucet, while the other, in due time, broke the galvanic circuit. As the glass tube was of comparatively small diameter, the water rushed into its interior, ascending as an unbroken column with great velocity and imparting to the wire the glass-hardness desired. According to Jarolimek²² this rapidity of current is of paramount importance when the attainment of extreme degrees of hardness is the desideratum. In the case of quiet water a non-conducting envelope of steam is apt to inclose the wire, protecting it against instantaneous chilling. Such a layer would effectually be torn away by a very swift current, and cold water and wire remain in more intimate contact. We regarded the hypothesis, which Jarolimek believes to have verified by experiment, as plausible.

Glass tubes of thin walls were chosen, and breakage was therefore a rare occurrence. Of course we did not keep the wire in the red-hot state longer than appeared absolutely necessary.

The operation of disadjusting and drying the parts of the apparatus after each chilling proved to be a tedious annoyance. Nevertheless the efficiency of the apparatus may be said to have been demonstrated by the fact that after a little experience we were able to temper 50 to 60 wires during an interval of five hours. Of the total number of hard wires obtained (some 180), those were selected for the measurements which had been operated upon during our later and more expert manipulation. The ends were broken off and discarded, and only as much of the central part of each wire used as would warrant the assumption of uniformity of hardness throughout the lengths employed. The degree of homogeneity, moreover, admits of being specially tested, as will be explained below.

The battery used consisted of 20–30 large Bunsen cells, connected in series or in multiple arc in a way to correspond with the external resistance. In the latter case it is necessary to keep the partial circuits as nearly as possible alike. Otherwise a reverse current is apt to traverse one of them, gradually disintegrating the carbons.

MEASUREMENT OF THERMO-ELECTRIC POWER.

Thermo-element.—The thermo-electric power of our wires was deduced from measurements of electromotive force and temperature, obtained by

²²Jarolimek: Dingle's Jour., CCXXI, pp. 436, 518, 1876.

combining them thermo-electrically with the same given normal wire. Chemically pure silver, deposited galvanoplastically, fused, drawn, and softened, appeared to be the most desirable metal-of-reference for this purpose. Two samples of this were selected and compared. From reasons of a practical character, however, we found it expedient not to use these normals in the actual work. In the measurements, a copper wire of a given kind, which had frequently and very carefully been compared with the silver, was substituted for it, and the thermo-electric powers steel-copper subsequently reduced to steel-silver, by calculation.

After testing many modifications, we adhered to the very efficient form of thermo-electric apparatus diagrammatically represented in figure 5. S_1 and S_2 are two doubly tubulated spherical receivers, of the

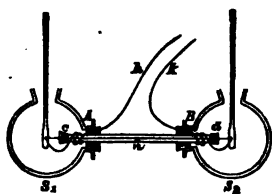


FIG. 5.—Form of thermo-element.

capacity 1 liter approximately. These were mounted on good non-conductors in such a way as to place the axes of the tubulures A and B in horizontal, the other two in vertical position. The former were provided with well-fitting corks, centrally perforated, so as to admit the glass tube cd (diam. 1 cm.) snugly. In this way the two receivers were held firmly together, and at distances apart adjustable at pleasure, thus adapting the arrangement for examination of a long or a short wire. Two small suitably-perforated corks, fitting the ends of the tube cd , gave to the wire an axial position within it. In this way the steel rods, exceedingly brittle and frail when in the state of glass-hardness, were adequately protected. Mention is still to be made of the terminals k and k of the apparatus. These were specially-selected samples of covered copper wire, as stated above. They passed through the large corks at A and B —in which they were cemented once for all—to the junctions at the center of the respective receivers. When a new rod was to be introduced, this was thrust through the tube cd , and the latter duly closed with the small corks, in the perforations of which the rod fitted tightly. Then the free ends of the terminals were connected with the respective ends of the steel rod, either by flat brass clamp-screws, or, where the temper permitted it, by soldering. The tube carrying the large corks was now in complete adjustment, and it was only necessary to insert these in the tubulures A and B of the receivers. One of the latter was then filled with water of the temperature of the room, the other with hot water. A woolen jacketing appropriately surrounding the hot receiver reduced the loss of heat by radiation to a minimum.

By the aid of two carefully calibrated thermometers, with their bulbs at the centers of the respective receivers, the temperature of these was read off. A small hole was drilled at n in the tube cd to allow for the expansion of the air heated by proximity to the hot water.

Method of measurement.—For the measurement of the thermo-electromotive force (expressed throughout in volts) a zero method was adopted. If E (figure 6) be the compensating (one Daniell), e the com-

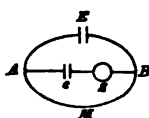


FIG. 6.—Disposition of thermo-electric apparatus.

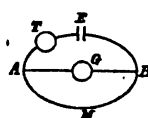


FIG. 7.—Apparatus for galvanometer-factor.

pensated element (the thermo-couple), W the resistance of AEB , w that of AMB , we shall have, when the current in AeB containing the galvanometer is zero,

$$\frac{e}{E} = \frac{w}{W + w}.$$

In our experiments, in the most unfavorable cases,

$$\frac{w}{W} = \frac{5}{10000};$$

and hence, with sufficient accuracy for the present purpose we may put

$$\frac{e}{E} = \frac{w}{W}.$$

Both w and W were furnished by Siemens' rheostats. The resistances of the connecting wires and of the Daniell are negligible. W could be increased to 30,000 ohms, w diminished as far as 0.1 ohm.

In order to eliminate such discrepancies as would arise from variations of the Daniell, the electromotive force of this element was measured before and after each observation. It is known that this source of error is by no means negligible, and that it depends on the way in which the Daniell has been put together, and on the time of use. For the purpose in question, the terminals of a Wiedemann's galvanometer of known factor A could be introduced into the circuit $EAMB$ with the aid of an appropriate key. If therefore the line ASB is broken, the resistance w excluded, we shall have a simple circuit $EAMB$ such that if n be the deflection at the galvanometer

$$E = A W n.$$

Usually $W = 20,000$ ohms was chosen, as it was through this resistance, approximately, that the Daniell acted during the measurements with the zero method.

To determine the factor A of the galvanometer we made use of a tangent-compass of known factor, C . This we calculated both from the dimensions of the coils and from voltametric observations. Figure 7

gives the disposition of apparatus diagrammatically, wherein E is the Daniell, T the tangent-compass, G the mirror-galvanometer. Let w be the resistance, i the intensity of current in the shunt $A M B$, W the resistance, and I the current in $A G B$; then

$$IW = iw;$$

whence

$$\frac{I}{I+i} = \frac{w}{W+w}.$$

But by measurement with the tangent compass we get

$$I+i = C \operatorname{tg} \varphi [1+f(\varphi)],$$

and with the galvanometer, simultaneously, $I = An$, whence

$$An = \frac{w}{W+w} C \operatorname{tg} \varphi [1+f(\varphi)].$$

By a proper choice of w and W , practically convenient deflections, both at the tangent compass and at the galvanometer, are obtainable. The determination of A was frequently repeated.

Essential details.—The actual arrangement of apparatus as given in figure 8 differs from the diagram (figure 6) described above, only in that serviceably-disposed commutators and keys have been introduced into the partial circuits.

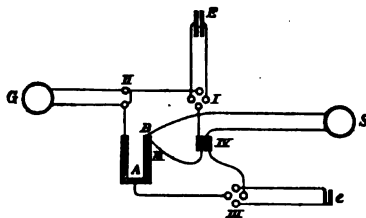


FIG. 8.—Details of thermo-electric apparatus.

The commutator I , inserted immediately after the Daniell, is used, in the first place, in determining the value of the electromotive force of this element from the double deflection of the mirror of the galvanometer G put in circuit by the key II . In the second place, when manipulated in connection with another commutator, III , which changes the direction of current of the thermo-element, it adds very materially to the attainable accuracy by enabling the observer practically to eliminate the discrepancies due to extraneous thermo-currents. These result from an irregular distribution of temperature in the connections. We actually measure not

$$\frac{e}{E} = \frac{w}{W}; \text{ but } \frac{e+\varepsilon}{E+\varepsilon'} = \frac{w}{W},$$

where ε and ε' are the disturbing electromotive forces in question. Now ε' , which has its seat in the branch $EAMB$, is always negligible in comparison with E . A similar assumption, however, by no means applies to ε —i. e., to the electromotive force which originates in the

branch *ASB*. This quantity, as our experiments have shown, very frequently reaches values amounting to a considerable part of e —indeed, when e is small, ε is directly comparable with it.

We therefore have

$$\frac{e + \varepsilon}{E} = \frac{w}{W}.$$

If both e and ε retained the same value before and after an observation there would result: Before commutation,

$$\frac{e + \varepsilon}{E} = \frac{w}{W};$$

after commutation,

$$\frac{e - \varepsilon}{E} = \frac{w^1}{W^1};$$

whence

$$\frac{e}{E} = \frac{1}{2} \left(\frac{w}{W} + \frac{w^1}{W^1} \right).$$

Now, although both e and ε do vary during the interval of an observation, the amount is small and the change of the former so nearly linear with the temperature T of the warm receiver, that the mean of the electromotive forces e may be regarded as coincident with the mean of the temperatures T . If the observations after commutation are rapidly made, which can easily be done because the approximate values of W and w are known from the first measurements, we may suppose ε to have remained constant.²³ A mean of the two determinations therefore will very nearly eliminate ε .

Finally, reference is still to be made to the form of Weber's commutator *IV*, which serves the purpose of a key of special kind. The small mercury cups are so filled that the thermo-current is not closed until a moment after the partial current from the Daniell. When w and W are properly chosen, therefore, the needle of the galvanometer *S* remains at rest. An exceedingly sensitive form of apparatus with an astatic needle, devised by Magnus and constructed by Sauerwald, was used here.

While one observer made the adjustments w and W , the other read off the temperatures of the thermometers in the receivers at given signals.

Calculation of constants.—If t and T be the temperatures of the thermo-electric junctions, e the corresponding electromotive force, we shall have generally²⁴

$$e = a(T - t) + b(T^2 - t^2) \quad . \quad . \quad . \quad (1)$$

Putting $T - t = x$, $T + t = u$, $e = y$,

$$y = ax + bxu \quad . \quad . \quad . \quad (2)$$

Inasmuch as the number of observations was always greater than two,

²³ By commutating again we frequently convinced ourselves that this supposition was quite permissible. The values obtained for the first and third positions of the commutators were so nearly identical that we could satisfactorily accept them as such.

²⁴ Avenarius: Pogg. Ann., CXIX, p. 406, 1863; *ibid.*, CXLIX, p. 374, 1873; Tait, Trans. R. Soc. Edinb., XXVII, 1872-73, p. 125. In this memoir the above equation is accepted merely as an empirical relation. Tait has discussed it theoretically.

the constants a and b were calculated by the method of least squares, on the basis of an equation of the form

$$\frac{y}{x} = a + bu.$$

We were led to choose this form not merely because the calculations are thus essentially simplified, but principally because the form (2) gives to the values of e , corresponding to great values of $T-t$, an amount of preference which appears to us wholly unwarranted: for although e is much more accurately measurable in the case of large values of $T-t$, the observed value of T will differ the more appreciably from the true temperature of the hot junction of the thermo-element, in proportion as T is greater than the temperature of the room in which the observations are made.

By aid of the well-known formulæ developed by the method of least squares, a , and b , of the thermo-couple copper-silver, were calculated from a large number of special observations.

By the same method, moreover, we derived the constants, a^1 , b^1 , for the elements steel-copper. To reduce from these the values a , b , which hold for the couples steel-silver, we made use of a set of tables calculated thus: If e , e^1 , e_0 correspond to a , a^1 , a_0 , we have

$$e = e^1 - e_0,$$

where e^1 is dependent on the arguments T and t . Now e_0 can be thus expressed:

$$e_0 = (a_0 T + b_0 T^2) - (a_0 t + b_0 t^2);$$

that is, as a difference between identical functions of the same arguments T and t . A table for

$$ax + bx^2$$

is therefore calculated once for all, from which for every combination of T and t the quantity e_0 , and therefore e , is easily obtained. After all the observations, e , had been referred to silver, the constants a and b were deduced by the thermo-electric formulæ above given.

MEASUREMENT OF ELECTRICAL CONDUCTIVITY.

Method calculation.—For the measurement of resistances we employed Kirchhoff's form of Wheatstone's bridge. The resistances w and δ to be compared could be exchanged by the aid of a mercury commutator. Heavy copper plates, the resistance α and ϵ of which was such as to introduce a very small correction only, connected the latter with an interposed commutator and finally with the end points of the bridge. The current was advantageously furnished by Weber's magnetic inductor. Sauerwald's sensitive apparatus, already referred to, was used as a galvanoscope.

The following is the method of calculation adopted:

$$\text{First position of commutator, } \frac{w+a}{\delta+\epsilon} = \frac{a_1}{b_1} = n_1;$$

$$\text{Second position of commutator, } \frac{w+\delta}{\delta+\alpha} = \frac{b_2}{a_2} = n_2;$$

whence

$$w = n_1\delta + n_1\epsilon - \alpha, \quad w = n_2\delta + n_2\alpha - \delta,$$

and therefore, if $\frac{1}{2}(n_1+n_2)=n$,

$$w = n\delta + (n-1)\frac{\alpha+\delta}{2} - \frac{n_1-n_2}{2}\frac{\alpha-\delta}{2}.$$

In the case of our bridge, at $t=10^\circ$

$$\frac{\alpha+\delta}{2} = 0.00194, \quad \frac{\alpha-\delta}{2} = -0.00016.$$

Now, in so far as n_1 and n_2 are always nearly identical, a sufficient approximation for w is furnished by the formula

$$w = n\delta + (n-1)\frac{\alpha+\delta}{2} \quad \dots \dots \dots (1)$$

In this way the calculations were greatly simplified, since n could be immediately obtained from Obach's²⁵ tables. A small table of our own contained the respective values of the term $(n-1)\frac{\alpha+\delta}{2}$.

In a part of the measurements we obtained excellent results with the beautiful method due to Hockin and Matthiessen.

From this value of w , the length and the diameter 2ρ —the latter dimension being determined microscopically—the specific resistance of the given wire at the temperature t followed at once.

The normal resistance δ was given by a specially constructed étalon of heavy German silver wire, soldered to stout terminals of copper properly amalgamated. We were in possession of six of these, such that by suitable combinations, either in series or in multiple arc, resistances as high as 0.6 ohms and as low as $\frac{1}{10}$ ohm were available. We were thus able to keep the sliding contact near the middle of the bridge wire, and the value of the factor $(n-1)$ in equation (1) was therefore invariably small.

Resistances at points of contact.—In view of the very small resistances (0.5 to 0.05 ohms) to be measured, great care had to be taken to reduce the resistances at the places where the steel wires were inserted to a minimum. To obtain an estimate as to the value of the discrepancies produced in this way we made a determination of the resistance of a soft steel wire for three different methods of insertion. In the first of these the wires were firmly held between flat clamp-screws; in the second, the ends of the wires were covered galvanoplastically with a thin even coat of copper, which was then amalgamated; finally, the contact was obtained by actually soldering the steel wires to pieces of heavy

²⁵ E. Obach: Hülftafeln für Messungen elektrischer Leitungswiderstände mittelst der Kirchhoff-Wheatstone'schen Drahtcombination, 1879.

copper wire. Only the last of these methods of insertion was found to be thoroughly satisfactory under all circumstances. In the first the error was quite large, while the second proved to be unsafe; for the amalgamated copper coat was apt to become insufficiently adhesive. In the case of glass-hard wire expeditions soldering is essential, otherwise the ends are annealed to an extent that will seriously affect the results. We avoided this at least partially by cooling the wire, immediately after the soldering had been effected, by a jet of water from a small wash-bottle. With a little practice the whole operation is finished in a few seconds. It is to be noted that if an error had been introduced in this way its effect would only have been that of giving further emphasis to the abnormally large results discussed in the sequel, since the values for specific resistance as thus actually found can only be short of the true values. In the later experiments all these inconveniences were avoided by the use of Hockin and Matthiessen's method.

Criterion for homogeneity.—The method just mentioned is peculiarly adapted for the determination of the degrees of uniformity of hardness along a given length of wire, because it enables the observer to compare the resistances of different parts of the said length with facility. The process as actually employed will be discussed in another chapter.

The method used for calibrating the essential wire of the bridge has been described elsewhere. (See appendix to this chapter, p. 72.)

. THE OPERATION OF SUDDEN COOLING. GLASS-HARDNESS.

Effect of chemical composition.—The steel rods tempered to glass-hardness in the manner described were found, on examination, to be thermo-electrically negative²⁶ relatively to silver.

In so far as the same process had been applied to rods nominally of like composition, it appeared plausibly presumable that the degrees of hardness attained would be nearly identical; in other words, that the tempering would have furnished us with a set of glass-hard rods of nearly the same thermo-electric power. This was not the case. A graphic representation of the relation between thermo-electromotive force and temperature showed this remarkable result, that the wires tempered were readily referable to a few distinct groups; for the position of the different thermo-electric curves was such as to permit them all to be comprehended by a few narrow and well-defined sectors. This implies that though the maximum of attainable hardness is different in the different wires, particular groups possessing nearly identical properties are readily discernible. We were unable to discover any relation between the individual members of the said groups and the

²⁶ Cf. preface, p. 6.

respective diameters of the wires. Nor did the wires hardened on any particular day show like thermo-electric qualities. It is conceivable, for instance, where currents of different intensity are employed, that the resulting difference in the degrees of red heat imparted to the wires would find its expression in a correspondingly marked difference in the degrees of hardness. The true cause of the difference of character observed must therefore be ascribed to chemical composition. In other words, the groups are distinguishable one from another by the respective amounts of carbon contained in the wires. The rods were not all received at the same time. Without doubt the maximum of hardness attainable by sudden chilling is essentially conditioned by the degree of carburization of the steel rod, and to a very small degree only by the impurities present. In a general way we may state that the maximum in question is a characteristic datum for the type of steel under experiment. In Chapter VII of the present memoir we shall have occasion to discuss this subject in detail.

Maximum hardness reached.—The greatest hardness met with in this work was that possessed by two rods of the diameters 0.056 cm. and 0.073 cm., respectively. The thermo-electric constant a here reached the exceptionally small value $a = -2.60$ (microvolts), and the specific resistance, at ordinary temperatures, was as large as 45 microhms, cm/cm². Unfortunately most of these very hard wires had to be discarded, because in the earlier experiments boiling water had been used in investigating their thermo-electric powers. We subsequently found that 100° produces a very pronounced annealing effect. In the later experiments with glass-hard wires water of only 40° was employed, and this but for a very short period of time.

Temperature of ignition.—Jarolimek and Ackermann²⁷ in their experiments on steel arrived at the important result that the rapidity of the first part of the chilling of red-hot steel, say from 600° or 700° to 300° or 400°, is far more essential as regards the degree of hardness obtained than the further cooling from 300°–400° to zero. It is easily possible to harden a rod very perceptibly by cooling it from bright redness in a metallic bath (Zn, Pb) at 400°. Such a process combines in one the operations of chilling and of annealing. Cooling from 300° or 400°, however, produces no effect. Again, Chernoff had previously found that if the temperature from which steel is chilled be supposed to increase continuously, no observable effect will be apparent until a temperature in dark cherry-red heat is reached, when glass-hardness is suddenly attained.²⁸

Our experience is in perfect accord with these results. The phenomenon was strikingly manifested both in rods of the same diameter and in

²⁷ Jarolimek u. Ackermann, Zeitschr. für das chem. Grossgewerbe, 1880. Similar results, we believe, were published by the distinguished American engineer, Mr. Joshua Rose, but we have been unable to find them.

²⁸ D. Chernoff: Vortrag gehalten in der russischen Technischen Gesellschaft, im April u. Mai 1868.

those of different diameters. In the first instance we may cite our observations with comparatively thick steel rods, which the available current was able to heat to dark redness only. After chilling these remained soft and pliable for more than one-third of their length; but at a particular point of the wire its mechanical condition changed suddenly to brittle hardness, and this despite the fact that during the heating a change of intensity of redness along the parts of the wire in question was scarcely discernible. In the second instance we frequently noted that where the intensity of current used was sufficient to impart hardness readily to a given comparatively thick class of wires, this was no longer possible for the next larger dimension, notwithstanding the fact that the respective thicknesses varied as little as 0.125 cm. and 0.145 cm. It is furthermore to be added that the sudden change in question is equally apparent both in the mechanical as well as in the electrical properties of steel.

The experiments made would certainly not warrant the forced assumption that the phenomenon in question partakes of the nature of a true discontinuity. Some molecular change occurring at an extremely rapid rate is alone to be understood. In a general way, however, it may be stated that a certain critical temperature in red heat must be surpassed if sudden cooling is to produce glass-hardness; otherwise the steel remains soft.

Thermo-electric maxima and neutral points.—In this place a final remark may be added. During the experiments we had frequent occasion to observe "neutral points" (occurring at the mean temperature $\frac{1}{2}(T+t) = \frac{a}{b}$ of the junctions of the thermo-element, the temperature at which the electromotive force passes with a change of sign through zero) of comparatively low value. Many of the hard rods differed but slightly from silver as regards their thermo-electric properties. Maxima of electromotive force at low temperatures were even more frequently obtained. A number of examples of this kind will be found in the tables below.

BEHAVIOR OF HARD STEEL RODS ANNEALED IN HOT OIL BATHS.

Manipulation.—Having thus in hand an assortment of glass-hard rods of excellent quality, it was our next endeavor to reduce the degrees of hardness of these consecutively by equal amounts. In other words, the problem was so to anneal the rods that between the glass-hard and the soft states as extremes a great number of intermediate approximately equidistant states might be obtained. We commenced our operations with this end in view by heating the hard steel in a large bath of linseed oil very gradually to different temperatures, re-

moving samples of the series of immersed rods at different stages of the process. Inequalities of temperature in the bath were reduced to a minimum by constant stirring. We also adopted an inverse method of procedure, in which, when a desired temperature was reached, the hard wires selected were submerged in the oil on a false bottom of wire gauze, and the whole allowed to cool. After several days they were examined both as to their thermo-electric power and their specific resistance.

Results.—The results of these measurements are given in the following table. It will be remembered that e (observed or calculated as specified) is the electromotive force in microvolts for the temperature T and t (centigrade) of the junctions. a and b are the thermo-electric constants of Avenarius, s , $\left(\frac{\text{cm}}{\text{cm}^2} t^{\circ} \text{microhm}\right)$ the specific resistance at the temperature t , ρ (cm.) finally the radius of the wires:

TABLE 7.—Thermo-electrics and conductivity of steel wires, annealed in oil baths.

Annealed at—	No.	t	T	$e:10^2$ observed.	$e:10^2$ calculated.	a	b	s $\frac{\text{cm}}{\text{cm}^2}$	t
		$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	microvolts.	microvolts.	microvolts.	microvolts.	microhm.	$^{\circ}\text{C.}$
I. 800°	No. 1 ($2\rho=0.0008$)	19.3	88.1	4.418	4.429	7.80	-0.0127	18.96	19
		19.3	74.0	3.632	3.615				
		19.3	68.8	2.982	2.971				
		19.3	50.1	2.125	2.131				
	No. 2 ($2\rho=0.0000$)	19.5	89.5	4.619	4.622	8.03	-0.0180	18.49	19
		19.5	76.2	3.849	3.845				
		19.5	62.0	2.961	2.950				
		19.5	54.3	2.457	2.458				
	No. 3 ($2\rho=0.0721$)	19.6	89.8	4.052	4.050	6.99	-0.0111	20.54	19
		19.7	73.3	3.194	3.191				
		19.6	59.1	2.406	2.414				
		19.7	50.1	1.893	1.888				
	No. 4 ($2\rho=0.0668$)	18.9	87.9	4.497	4.503	7.78	-0.0118	20.00	19
		18.9	70.8	3.468	3.462				
		18.9	67.4	2.657	2.651				
		18.9	48.3	2.052	2.056				
	No. 5 ($2\rho=0.0845$)	19.7	86.7	4.787	4.789	8.52	-0.0180	17.84	19
		19.7	72.1	3.947	3.943				
		19.7	59.4	2.975	2.977				
		19.7	50.6	2.353	2.352				
II. 775° ...	No. 6 ($2\rho=0.0008$)	20.0	89.2	3.987	3.985	7.24	-0.0185	20.75	20
		20.0	78.2	3.437	3.436				
		20.0	64.9	2.781	2.783				
		20.0	50.9	1.941	1.940				
	No. 7 ($2\rho=0.0658$)	20.0	90.1	3.553	3.562	6.15	-0.0097	22.74	19
		20.0	71.9	2.737	2.729				
		20.0	59.7	2.141	2.134				
		20.0	48.3	1.529	1.533				
III. 250° ..	No. 8 ($2\rho=0.0880$)	19.9	88.0	3.429	3.427	6.46	-0.0132	23.20	19
		19.9	74.8	2.863	2.860				
		19.9	61.6	2.237	2.244				
		19.9	51.9	1.767	1.763				
	No. 9 ($2\rho=0.0720$)	20.0	80.5	3.462	3.457	6.96	-0.0124	20.47	19
		20.0	65.8	2.697	2.701				
		20.0	55.3	2.124	2.128				
		20.0	49.9	1.627	1.622				

TABLE 7.—Thermo-electrics and conductivity of steel wires, annealed in oil baths—Cont'd.

Annealed at—	No.	t	T	$e:10^2$ observed.	$e:10^2$ calculated.	a	b	a_1	t
		$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	microvolts.	microvolts.	microvolts.	microvolts.	$\frac{\text{cm. t}}{\text{cm}^2}$ microhm.	$^{\circ}\text{C.}$
IV. 225°...	No. 10 ($2\rho=0.0720$)	20.0	79.9	2.161	2.156	4.67	-0.0007	25.66	19
		20.0	68.4	1.803	1.804				
		20.0	57.3	1.235	1.340				
		20.0	49.0	1.144	1.141				
	No. 11 ($2\rho=0.0565$)	20.1	87.1	2.663	2.672	5.15	-0.0109	24.81	19
		20.1	65.9	1.948	1.931				
		20.1	53.9	1.464	1.469				
		20.1	41.8	0.971	0.972				
	No. 12 ($2\rho=0.0548$)	20.1	89.4	3.442	3.434	6.40	-0.0131	22.93	19
		20.1	67.9	2.494	2.503				
		20.1	55.8	1.900	1.902				
		20.1	44.8	1.872	1.869				
	No. 13 ($2\rho=0.0337$)	20.1	87.4	3.770	3.769	6.89	-0.0121	20.66	19
		20.1	74.0	3.105	3.107				
		20.1	62.4	2.498	2.498				
		20.1	52.0	1.922	1.923				
V. 200°....	No. 14 ($2\rho=0.0900$)	19.9	89.2	2.059	2.068	4.06	-0.0096	27.36	20
		19.9	75.6	1.751	1.737				
		19.9	64.4	1.434	1.437				
		19.9	54.9	1.161	1.163				
	No. 15 ($2\rho=0.0558$)	20.1	89.5	1.989	1.989	3.85	-0.0090	28.11	19
		20.1	68.8	1.484	1.489				
		20.1	69.1	1.231	1.225				
		20.1	50.1	0.963	0.965				
	No. 16 ($2\rho=0.0974$)	18.9	89.8	2.524	2.528	4.67	-0.0103	26.70	19
		18.9	74.3	2.063	2.063				
		18.9	61.1	1.631	1.626				
		18.9	51.7	1.294	1.297				
	No. 17 ($2\rho=0.0882$)	18.9	82.5	2.056	2.056	4.26	-0.0102	27.93	19
		19.0	68.8	1.681	1.678				
		18.9	59.8	1.414	1.417				
		19.0	51.9	1.166	1.165				
	No. 18 ($2\rho=0.0723$)	19.1	78.8	1.314	1.312	2.79	-0.0060	31.32	19
		19.1	68.2	1.109	1.112				
		19.1	57.8	0.899	0.900				
		19.1	48.7	0.706	0.705				
	No. 19 ($2\rho=0.0560$)	18.1	82.0	1.859	1.862	3.53	-0.0091	28.68	19
		18.1	62.8	1.387	1.381				
		18.1	47.8	0.954	0.958				
		18.2	39.8	0.714	0.713				
VI. 175°...	No. 20 ($2\rho=0.0336$)	18.3	76.8	2.723	2.715	5.45	-0.0086	24.34	19
		18.3	62.3	2.088	2.098				
		18.3	52.9	1.680	1.677				
		18.3	42.1	1.177	1.176				
	No. 21 ($2\rho=0.0908$)	18.8	86.4	1.822	1.809	3.76	-0.0103	29.34	19
		18.8	67.1	1.866	1.388				
		18.8	53.8	1.061	1.054				
		18.8	43.3	0.765	0.703				
	No. 22 ($2\rho=0.0571$)	18.8	87.2	1.784	1.729	3.41	-0.0083	30.94	19
		18.9	72.4	1.414	1.417				
		18.8	59.7	1.122	1.126				
		18.9	48.8	0.854	0.850				
VII. 150°	No. 23 ($2\rho=0.0385$)	18.5	73.7	1.745	1.744	4.24	-0.0117	27.93	19
		18.5	60.4	1.887	1.890				
		18.5	52.1	1.146	1.147				
		18.5	45.4	0.941	0.939				

Digest.—If we arrange these different degrees of hardness, expressed both thermo-electrically and in terms of their specific resistance, with reference to continuous variation of the former quantity, we obtain

the following perspicuous tabular comparison. The table shows that our endeavor to reach a great number of symmetrically distributed degrees of hardness systematically, was only partially successful.

TABLE 8.—*Thermo-electric position and conductivity of annealed steel.*

No.	α	s	Annealed at	No.	α	s	Annealed at
	<i>microvolts.</i>	<i>microhms.</i>	$^{\circ}\text{C.}$		<i>microvolts.</i>	<i>microhms.</i>	$^{\circ}\text{C.}$
5.....	8.52	17.64	300	11.....	5.15	24.81	250
2.....	8.03	18.49	300	16.....	4.67	26.70	200
1.....	7.80	18.96	300	10.....	4.67	25.66	250
4.....	7.78	20.00	300	17.....	4.26	27.93	200
6.....	7.24	20.75	275	23.....	4.24	27.98	150
3.....	6.99	20.54	300	14.....	4.06	27.36	225
9.....	6.96	20.47	250	15.....	3.85	28.11	225
13.....	6.89	20.66	250	19.....	3.83	28.68	200
8.....	6.46	22.20	250	21.....	3.76	29.84	175
12.....	6.40	22.93	250	22.....	3.41	30.94	175
7.....	6.15	22.74	275	18.....	2.70	31.33	200
20.....	5.45	24.34	200				

ON THE BEARING OF THE TIME OF EXPOSURE ON THE EFFICACY OF ANNEALING.

Low annealing temperatures.—In the foregoing experiments the lowest temperature employed was 150° . It will be seen that the annealing effect thus produced is strikingly large. This observation naturally suggested the question as to what results are to be expected when the annealing is conducted even at lower temperatures. The inquiry would have an immediate practical bearing: It will be remembered that in the thermo-electric measurements it is desirable to raise one of the junctions to a high temperature relatively to the other. We are led to ask, therefore, how high this temperature may be chosen without destroying uniformity of temper and producing partial annealing at one end of the rod.

Results for 100° .—We began the preliminary experiments with the two rods, Nos. 24 and 25, of nearly the same thicknesses, 0.0574 cm. and 0.0554 cm., respectively, but of different degrees of glass-hardness. Thermo-electric measurements only were made, with results for the glass-hard state as follows:

TABLE 9.—*Thermo-electric power of glass-hard wires.*

	t	T	$\epsilon:10^8$ observed.	$\epsilon:10^8$ calculated.	α	δ
	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	<i>microvolt.</i>	<i>microvolt.</i>	<i>microvolt.</i>	<i>microvolt.</i>
No. 24.....	12.5	88.1	-2.809	-2.793	-2.83	-0.0096
	12.5	78.8	-2.376	-2.396		
	12.5	58.1	-1.572	-1.567		
	12.6	44.1	-1.139	-1.139		
No. 25.....	12.3	89.0	-0.707	-0.697	+0.13	-0.0108
	12.4	80.1	-0.652	-0.554		
	12.4	71.2	-0.415	-0.428		
	12.4	59.8	-0.294	-0.289		

These wires were now exposed to the action of steam at 100° for a period of one hour, in an ordinary boiling-point apparatus. The measurement of thermo-electric position made on the following day showed these values:

TABLE 10.—*Hard wires, 1^h at 100° .*

	t	T	$\epsilon : 10^2$ observed.	$\epsilon : 10^2$ calculated.	a	b
	$^{\circ}C.$	$^{\circ}C.$	microvolt.	microvolt.	microvolt.	microvolt.
No. 24 ¹	18.9	58.4	-0.069	-0.069	+0.61	-0.0102
	18.9	50.7	-0.025	-0.025		
	18.9	45.2	-0.005	-0.005		
	18.9	39.8	+0.008	+0.008		
No. 25	18.9	76.1	1.030	1.029	+2.75	-0.0100
	18.9	65.2	0.893	0.890		
	18.9	54.7	0.750	0.746		
	18.9	44.0	0.599	0.600		

¹ Neutral point: $(T+t) = -\frac{a}{b} = 60^{\circ}.2$; $\therefore T = 48^{\circ}.3$.

From a comparison of the values of a before and after annealing at 100° , a variation of thermo-electric power, therefore also of mechanical state, is very strikingly apparent; whence it follows at once that in the measurements of ϵ , the use of boiling water in the hot receiver in the case of very hard wires is under no circumstances permissible. Indeed, from the magnitude of the variation in question, we infer that temperatures even much lower than 100° will show a tendency to produce an annealing effect seriously detrimental to a uniformity of the temper of the wire.

The above experiment was repeated. The rods were again annealed at 100° for a period of one hour, and thermo-electrically examined on the following day.

TABLE 11.—*Hard wires, 2^h at 100° .*

	t	T	$\epsilon : 10^2$ observed.	$\epsilon : 10^2$ calculated.	a	b
	$^{\circ}C.$	$^{\circ}C.$	microvolt.	microvolt.	microvolt.	microvolt.
No. 24 ²	17.4	78.8	0.142	0.152	1.26	-0.0110
	17.4	64.7	0.184	0.174		
	17.4	56.1	0.183	0.178		
	17.3	49.8	0.162	0.167		
No. 25	17.3	71.1	1.256	1.249	3.64	-0.0150
	17.3	61.6	1.093	1.092		
	17.4	53.4	0.918	0.932		
	17.4	46.7	0.794	0.787		

² Maximum at $T = -\frac{a}{b} = 57^{\circ}.8$; observed, $y = 18.5$; calc., $y = 17.8$.

The results again show a smaller but nevertheless clearly pronounced variation of thermo-electric power, and we arrive at the important conclusion that, in addition to the temperature of the annealing bath, a second factor is essential in conditioning the resultant hardness, namely, the interval of *time* during which the annealing is prolonged, or the rod exposed to the given temperature.

With the object of discovering the nature of this time-effect, the experiments were continued in the same way. The results are contained in the following tables:

TABLE 12.—*Hard wires 3^h at 100°.*

	<i>t</i>	<i>T</i>	$\epsilon : 10^3$ observed.	$\epsilon : 10^3$ calculated.	<i>a</i>	<i>b</i>
	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	microvolt.	microvolt.	microvolt.	microvolt.
No. 24	17.5	74.1	0.329	0.327	0.161	-0.0111
	17.5	62.0	0.316	0.318		
	17.5	54.2	0.294	0.294		
	17.5	48.6	0.270	0.269		
No. 25	17.5	74.3	1.499	1.497	3.55	-0.0100
	17.5	62.7	1.242	1.245		
	17.5	53.8	1.033	1.033		
	17.5	49.2	0.926	0.926		

TABLE 13.—*Hard wires 4^h at 100°.*

	<i>t</i>	<i>T</i>	$\epsilon : 10^3$ observed.	$\epsilon : 10^3$ calculated.	<i>a</i>	<i>b</i>
	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	microvolt.	microvolt.	microvolt.	microvolt.
No. 24	17.7	86.4	0.484	0.487	1.76	-0.0101
	17.7	77.5	0.480	0.477		
	17.7	66.4	0.444	0.445		
	17.7	54.7	0.379	0.379		
No. 25	17.7	87.4	1.886	1.887	3.77	-0.0102
	17.7	76.1	1.660	1.648		
	17.7	67.7	1.447	1.453		
	17.7	56.5	1.177	1.182		

TABLE 14.—*Hard wires 5^h at 100°.*

	<i>t</i>	<i>T</i>	$\epsilon : 10^3$ observed.	$\epsilon : 10^3$ calculated.	<i>a</i>	<i>b</i>
	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	microvolt.	microvolt.	microvolt.	microvolt.
No. 24	17.0	71.6	0.500	0.502	1.70	-0.0075
	17.0	58.4	0.477	0.468		
	17.0	44.5	0.326	0.340		
	17.0	34.5	0.203	0.228		
No. 25	17.1	75.0	1.661	1.665	3.90	-0.0111
	17.1	62.1	1.363	1.358		
	17.1	53.6	1.136	1.138		
	17.1	47.0	0.952	0.954		

TABLE 15.—*Hard wires 6^h at 100°.*

	<i>t</i>	<i>T</i>	$\epsilon : 10^3$ observed.	$\epsilon : 10^3$ calculated.	<i>a</i>	<i>b</i>
	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	microvolt.	microvolt.	microvolt.	microvolt.
No. 24	17.5	82.6	0.637	0.641	1.92	-0.0093
	17.5	57.1	0.483	0.483		
	17.5	40.7	0.319	0.329		
	17.5	33.9	0.230	0.236		
No. 25	17.4	72.0	1.628	1.632	4.02	-0.0115
	17.4	48.7	1.018	1.019		
	17.4	30.8	0.648	0.642		
	17.4	27.5	0.351	0.355		

Digest.—The relation between a and the time of exposure is more perspicuously apparent in the following comparison:

		0 ^h	1 ^h	2 ^h	3 ^h	4 ^h	5 ^h	6 ^h
(24)	$a =$	-2.88	+0.61	1.26	1.61	1.76	1.70	1.92
(25)	$a =$	+0.13	2.75	3.64	3.55	3.77	3.99	4.08

From this grouping of parallel results, or, more evidently still, from a graphic representation (time as abscissa, thermo-electric constant as ordinate, mean values of Nos. 24 and 25, figure 9), it will be seen that

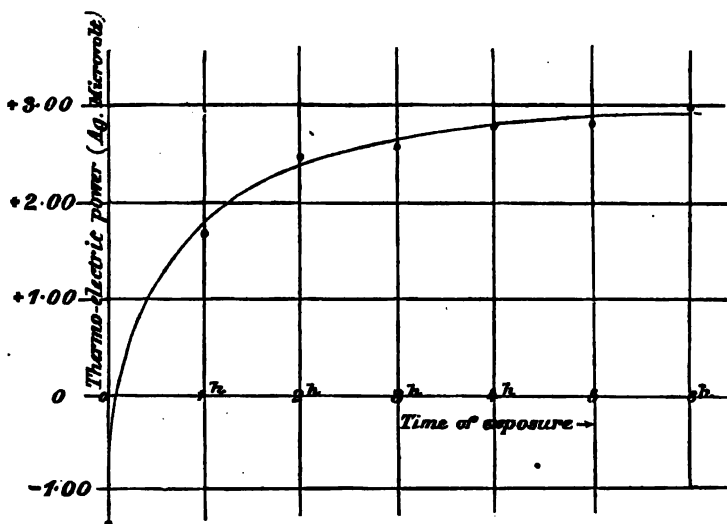


FIG. 9.—Hard wires annealed for six consecutive hours in steam at 100°.

hardness varies continuously with the time of exposure of the glass-hard rod to the given annealing temperature; that the amount of thermo-electric change rapidly decreases as the time increases, until finally a definite and superior limiting value is asymptotically reached.²⁹

After these introductory experiments we determined to investigate

²⁹ Among the above results the individual values of a , 1.70 for the first and 3.77 for the second rod, require comment. It is obvious that from the four observations for each, probably affected with larger errors than usual, the method of least squares has not derived the constants in closest accordance with fact. This betrays itself in the values obtained for b , which differ largely from the average values. The constant b varies but slightly (as a general mean $-b=0.0100$ may be accepted). Associated with the values of a in question, however, we have $-b=0.0075$ (corresponding to the small result $a=1.70$) and $-b=0.0102$ (corresponding to the large result $a=3.77$). But in view of the fact that the function of which a is the coefficient is positive, and that in which b is involved, negative, the errors of both a and b are partially eliminated in the sum, so that observed ϵ and calculated ϵ are again in satisfactory accordance.

the phenomena of annealing more rigidly, giving the effect of time of exposure due prominence. Besides the boiling point of water, that of methyl alcohol at 66° 0 and that of aniline at 185° were chosen for annealing, the wires being suspended in vapors of these substances circulating in a glass boiling-point apparatus. A still higher temperature (330°) was furnished by the melting point of lead. Batches of three wires of different diameters and different degrees of glass-hardness were selected to be annealed respectively at each of these temperatures. To trace the effects resulting, simultaneous determinations, both of thermo-electric power and conductivity, were made at as many stages of the process as appeared desirable. The data are contained in the tables 16-28.

BEHAVIOR OF HARD STEEL ANNEALED IN VAPOR OF BOILING METHYL ALCOHOL (66°).

The rods selected were:

No. 28; diameter (2ρ)=0.0827 cm.,

No. 29; diameter (2ρ)=0.0631 cm.,

No. 30; diameter (2ρ)=0.0479 cm.

After the thermo-electric power (microvolts) and specific resistance (microhms) for the glass-hard state had been determined, the wires were subjected to the annealing influence of vapor of methyl alcohol at 66° for three consecutive hours, and at the end of each hour examined by the aid of the electrical qualities in question. The results are these:

TABLE 16.—*Hard steel annealed at 66°.*

[Rod No. 28. $2\rho=0.0827$.]

Remarks.	t	T	$\epsilon:10^3$ observed.	$\epsilon:10^3$ calculated.	α	b	ϵ	t
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{\text{cm}}{\text{cm}^2} \times 10^3$ microhm.	°C.
Glass-hard.....	18.7	54.8	-1.003	-0.999	-2.56	-0.0064	42.64	18
	18.7	48.9	-0.907	-0.904				
	18.7	43.4	-0.721	-0.711				
	18.7	35.6	-0.495	-0.492				
1 ^h in vapor of methyl alcohol, $t=66^\circ.0$.	18.1	58.2	-1.033	-1.027	-1.94	-0.0111	42.55	18
	18.1	52.4	-0.962	-0.937				
	18.1	47.9	-0.792	-0.798				
	18.1	42.0	-0.620	-0.626				
1 ^h more in vapor of methyl alcohol, $t=66^\circ.0$.	18.3	58.5	-0.968	-0.964	-1.81	-0.0107	42.45	19
	18.4	49.4	-0.785	-0.787				
	18.3	42.9	-0.601	-0.608				
	18.4	38.7	-0.497	-0.492				
1 ^h more in vapor of methyl alcohol, $t=66^\circ.0$.	20.0	60.6	-0.956	-0.947	-1.58	-0.0122	42.55	19
	20.0	51.5	-0.767	-0.774				
	20.0	46.4	-0.625	-0.632				
	20.0	39.4	-0.453	-0.448				

TABLE 17.—*Hard steel annealed at 66°.*[Rod No. 29. $2p=0.0631$.]

Remarks.	t	T	$\epsilon: 10^3$ observed.	$\epsilon: 10^3$ calculated.	a	b	s_1	t
	$^{\circ}C.$	$^{\circ}C.$	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{cm}{cm^{1.5}}$ microhm.	$^{\circ}C.$
Glass-hard	18.7	50.4	-0.696	-0.697	-1.90	-0.0044	42.08	17
	18.8	44.5	-0.564	-0.559				
	18.7	38.8	-0.429	-0.432				
	18.8	34.8	-0.343	-0.343				
1^b in vapor of methyl alcohol, $t=66^{\circ}0$.	18.2	57.7	-0.704	-0.702	-1.25	-0.0076	41.70	18
	18.2	51.7	-0.579	-0.581				
	18.2	45.8	-0.467	-0.467				
	18.2	40.4	-0.378	-0.378				
1^b more in vapor of methyl alcohol, $t=66^{\circ}0$.	18.5	57.2	-0.686	-0.689	-0.91	-0.0098	41.52	19
	18.5	49.4	-0.487	-0.486				
	18.5	43.9	-0.385	-0.387				
	18.5	40.1	-0.324	-0.321				
1^b more in vapor of methyl alcohol, $t=66^{\circ}0$.	19.9	61.4	-0.624	-0.620	-0.70	-0.0098	41.42	19
	19.9	53.2	-0.469	-0.471				
	19.9	45.3	-0.334	-0.340				
	19.9	41.1	-0.280	-0.275				

TABLE 18.—*Hard steel annealed at 66°.*[Rod No. 30. $2p=0.0479$.]

Remarks.	t	T	$\epsilon: 10^3$ observed.	$\epsilon: 10^3$ calculated.	a	b	s_1	t
	$^{\circ}C.$	$^{\circ}C.$	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{cm}{cm^{1.5}}$ microhm.	$^{\circ}C.$
Glass-hard	18.7	54.2	-0.335	-0.329	-0.42	-0.0071	37.08	18
	18.7	45.3	-0.228	-0.229				
	18.7	40.2	-0.175	-0.178				
	18.7	34.4	-0.126	-0.124				
1^b in vapor of methyl alcohol, $t=66^{\circ}0$.	17.8	56.9	-0.209	-0.209	-0.01	-0.0070	36.80	18
	20.1	45.1	-0.117	-0.117				
1^b more in vapor of methyl alcohol, $t=66^{\circ}0$.	19.2	59.1	-0.105	-0.103	+0.30	-0.0074	36.51	18
	19.2	54.5	-0.079	-0.079				
	19.2	49.0	-0.054	-0.055				
	19.2	42.6	-0.031	-0.032				
	19.2	38.4	-0.023	-0.021				
1^b more in vapor of methyl alcohol, $t=66^{\circ}0$. ¹	19.8	54.6	-0.003	-0.002	+0.47	-0.0065	36.42	19
	19.9	49.7	+0.009	+0.008				
	19.8	45.0	0.015	0.014				
	19.9	38.2	0.018	0.018				

¹Neutral point: $(T+t)=-\frac{a}{b}=72.5$; $\therefore T=52^{\circ}7$.

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BEHAVIOR OF HARD STEEL ANNEALED IN STEAM (100°).

The rods selected were:

No. 31; diameter (2ρ)=0.0833 cm.,

No. 32; diameter (2ρ)=0.0616 cm.,

No. 33; diameter (2ρ)=0.0491 cm.

Our earlier experiments with rods Nos. 24 and 25 had shown that the effect of annealing in steam is particularly marked during the first hour of exposure. We therefore decided to obtain intermediate stages by making interruptions and examinations after each of the first 10, 30, and 60 minutes of this interval. After this the rods were annealed during two hours more, as above. The results for the hardness in the original (glass-hard) and subsequent states are fully given in the following tables:

TABLE 19.—*Hard steel annealed at 100°.*

[Rod No. 31. $2\rho = 0.0833$.]

Remarks.	t	T	$\epsilon : 10^2$ observed.	$\epsilon : 10^2$ calculated.	a	b	n	ϵ
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{\text{cm}}{\text{cm}^2} t$ microhm.	°C.
Glass-hard	22.5	53.2	-0.621	-0.624	-1.20	-0.0093	40.47	21
	22.5	51.3	-0.542	-0.539				
	22.4	44.9	-0.410	-0.409				
	22.4	39.6	-0.303	-0.304				
10 ^m in steam at 100°	19.7	61.0	-0.335	-0.332	-0.08	-0.0090	39.05	20
	19.7	55.4	-0.298	-0.299				
	19.7	48.7	-0.202	-0.202				
	19.7	42.9	-0.150	-0.150				
20 ^m more in steam at 100°.	18.5	76.0	-0.177	-0.170	+0.55	-0.0099	37.64	19
	18.5	65.7	-0.094	-0.095				
	18.5	49.4	-0.009	-0.018				
	18.5	37.5	+0.006	+0.009				
30 ^m more in steam at 100°.	18.1	63.5	+0.122	+0.124	0.86	-0.0072	36.33	19
	18.1	56.9	0.126	0.125				
	18.1	50.0	0.118	0.118				
	18.1	44.5	0.107	0.107				
1 ^h more in steam at 100° ..	18.2	72.4	0.330	0.329	1.55	-0.0104	35.38	18
	18.2	58.8	0.304	0.304				
	18.3	51.0	0.270	0.271				
	18.3	45.4	0.242	0.241				
1 ^h more in steam at 100° ..	19.2	71.4	0.457	0.455	1.81	-0.0103	34.72	18
	19.3	61.4	0.410	0.410				
	19.2	55.2	0.371	0.374				
	19.3	47.2	0.314	0.312				

(641)

TABLE 20.—*Hard steel annealed at 100°.*[Rod No. 32. $2p = 0.0616$.]

Remarks.	<i>t</i>	<i>T</i>	$\epsilon: 10^2$ observed.	$\epsilon: 10^2$ calculated.	<i>a</i>	<i>b</i>	$\epsilon:$ $\frac{\text{cm}}{\text{cm}^2 t}$ microhm.	<i>t</i>
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.		°C.
Glass-hard	20.7	50.7	—0.659	—0.659	—1.44	—0.0106	41.42	21
	20.7	46.0	—0.545	—0.544				
	20.7	41.9	—0.437	—0.448				
10" in steam at 100°	19.2	56.7	—0.269	—0.266	—0.39	—0.0042	39.53	20
	19.3	53.4	—0.235	—0.238				
	19.2	44.7	—0.168	—0.168				
	19.3	40.4	—0.137	—0.136				
20" more in steam at 100° ¹ .	18.5	70.1	0.075	0.075	0.80	—0.0075	38.02	19
	18.5	63.6	0.090	0.088				
	18.6	56.0	0.094	0.094				
	18.6	44.8	0.088	0.088				
30" more in steam at 100°.	18.0	59.1	0.291	0.294	1.39	—0.0086	36.33	19
	18.0	49.6	0.260	0.253				
	18.0	44.7	0.225	0.225				
	18.0	41.4	0.201	0.203				
1 ¹ more in steam at 100°..	17.7	55.7	0.519	0.519	2.01	—0.0089	35.19	18
	17.7	49.5	0.451	0.451				
	17.7	41.8	0.357	0.359				
	17.7	36.4	0.288	0.287				
1 ¹ more in steam at 100°..	19.2	67.3	0.754	0.754	2.26	—0.0080	34.34	18
	19.3	58.9	0.650	0.648				
	19.2	52.0	0.556	0.556				
	19.2	45.8	0.463	0.463				

¹ Maximum at $T = -\frac{1}{2} \frac{a}{b} = 53^\circ.1$.TABLE 21.—*Hard steel annealed at 100°.*[Rod No. 33. $2p = 0.0491$.]

Remarks.	<i>t</i>	<i>T</i>	$\epsilon: 10^2$ observed.	$\epsilon: 10^2$ calculated.	<i>a</i>	<i>b</i>	$\epsilon:$ $\frac{\text{cm}}{\text{cm}^2 t}$ microhm.	<i>t</i>
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.		°C.
Glass-hard	20.5	57.0	—0.379	—0.381	—0.07	—0.0122	36.98	21
	20.6	52.3	—0.307	—0.306				
	20.6	45.9	—0.236	—0.224				
	20.6	41.2	—0.170	—0.171				
10" in steam at 100°	19.2	58.6	0.151	0.150	0.97	—0.0076	35.00	20
	19.2	51.7	0.142	0.142				
	19.2	44.4	0.124	0.124				
	19.2	37.8	0.100	0.100				
20" more in steam at 100°.	18.4	53.2	0.361	0.364	1.50	—0.0062	33.58	19
	18.4	44.7	0.294	0.290				
	18.4	37.5	0.221	0.218				
	18.4	32.5	0.163	0.166				
30" more in steam at 100°.	18.0	56.3	0.632	0.634	2.25	—0.0079	32.26	19
	18.1	47.8	0.517	0.510				
	18.0	41.9	0.418	0.423				
	18.1	32.0	0.256	0.257				
1 ¹ more in steam at 100°..	18.0	66.1	0.881	0.893	2.67	—0.0097	31.22	18
	18.0	58.6	0.795	0.783				
	18.0	51.4	0.670	0.668				
	18.0	42.1	0.500	0.504				
1 ¹ more in steam at 100°..	19.3	67.3	1.071	1.070	3.00	—0.0090	30.67	18
	19.3	58.1	0.895	0.897				
	19.3	50.2	0.737	0.737				
	19.3	40.8	0.521	0.521				

BEHAVIOR OF HARD STEEL ANNEALED IN VAPOR OF BOILING ANILINE.(185°).

The details of the operations in this case were the same as those described in the foregoing paragraph. The rods used were:

No. 34; diameter (2ρ)=0.0835 cm.,

No. 35; diameter (2ρ)=0.0627 cm.,

No. 36; diameter (2ρ)=0.0481 cm.

The results obtained are the following:

TABLE 22.—*Hard steel annealed at 185°.*

[Rod No. 34. $2\rho=0.0835$.]

Remarks.	t	T	$\epsilon: 10^3$ observed.	$\epsilon: 10^3$ calculated.	a	b	a	t
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{\text{cm}}{\text{cm}^2}$ microhm.	°C.
Glass-hard	22.1	59.2	-0.573	-0.569	-0.83	-0.0087	39.84	21
	22.1	51.1	-0.422	-0.425				
	22.1	44.2	-0.313	-0.313				
	22.0	39.5	-0.239	-0.238				
10" in vapor of aniline at 185°.	19.5	71.0	1.414	1.423	3.59	-0.0090	29.25	20
	19.5	62.8	1.235	1.228				
	19.5	52.8	0.981	0.975				
	19.5	43.6	0.722	0.726				
30" more in vapor of aniline at 185°.	18.7	77.5	2.694	2.700	4.10	-0.0116	28.02	19
	18.7	59.8	1.321	1.312				
	18.7	49.7	1.025	1.027				
	18.7	42.9	0.817	0.820				
30" more in vapor of aniline at 185°.	18.2	71.0	1.717	1.721	4.33	-0.0121	27.17	19
	18.2	65.1	1.568	1.562				
	18.2	56.9	1.325	1.327				
	18.2	45.9	0.966	0.986				
1" more in vapor of aniline at 185°.	18.2	76.9	2.054	2.052	4.61	-0.0118	26.32	18
	18.2	68.2	1.895	1.899				
	18.2	61.1	1.579	1.581				
	18.2	52.5	1.298	1.297				
1" more in vapor of aniline at 185°.	19.3	88.5	2.453	2.454	4.84	-0.0121	25.85	18
	19.3	74.3	2.043	2.045				
	19.3	65.9	1.782	1.779				
	19.3	58.4	1.526	1.528				

TABLE 23.—*Hard steel annealed at 185°.*[Rod No. 35. $2\rho=0.0627$.]

Remarks.	t	T	$\epsilon: 10^2$ observed.	$\epsilon: 10^2$ calculated.	a	b	a	t
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{\text{cm}}{\text{cm}^2}$ microhm.	°C.
Glass-hard.....	22.1	58.5	—0.847	—0.846	—1.97	—0.0059	42.45	21
	22.2	50.4	—0.680	—0.684				
	22.1	44.4	—0.538	—0.534				
	22.1	39.1	—0.402	—0.402				
10" in vapor of aniline at 185°.	19.8	65.0	1.531	1.532	4.22	—0.0097	28.58	20
	19.9	57.0	1.292	1.297				
	19.9	49.2	1.032	1.038				
	19.9	42.6	0.821	0.819				
20" more in vapor of aniline at 185°.	18.5	75.6	2.078	2.081	4.75	—0.0118	27.26	19
	18.5	66.6	1.812	1.808				
	18.6	56.2	1.453	1.455				
	18.6	45.7	1.082	1.078				
30" more in vapor of aniline at 185°.	18.1	72.7	2.189	2.189	5.18	—0.0128	26.04	19
	18.1	63.2	1.861	1.863				
	18.1	56.0	1.604	1.609				
	18.1	48.0	1.294	1.294				
1" more in vapor of aniline at 185°.	18.3	69.4	2.226	2.223	5.42	—0.0122	25.29	18
	18.3	62.6	1.962	1.964				
	18.3	55.4	1.689	1.686				
	18.3	45.3	1.256	1.254				
1" more in vapor of aniline at 185°.	19.2	73.5	2.452	2.450	5.64	—0.0122	24.72	18
	19.3	66.2	2.155	2.158				
	19.2	57.6	1.806	1.807				
	19.3	48.7	1.415	1.414				

TABLE 24.—*Hard steel annealed at 185°.*[Rod No. 36. $2\rho=0.0481$.]

Remarks.	t	T	$\epsilon: 10^2$ observed.	$\epsilon: 10^2$ calculated.	a	b	a	t
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{\text{cm}}{\text{cm}^2}$ microhm.	°C.
Glass-hard.....	20.3	51.2	—0.279	—0.279	—0.05	—0.0121	37.17	21
	20.4	46.6	—0.222	—0.222				
	20.3	41.8	—0.171	—0.170				
	20.4	38.6	—0.137	—0.138				
10" in vapor of aniline at 185°.	19.2	71.8	2.069	2.071	4.76	—0.0091	25.85	20
	19.2	63.7	1.793	1.787				
	19.2	57.4	1.552	1.555				
	19.2	49.4	1.251	1.250				
20" more in vapor of aniline at 185°.	18.5	78.5	2.485	2.483	5.26	—0.0115	24.91	19
	18.5	64.3	1.968	1.971				
	18.5	54.9	1.609	1.605				
	18.5	45.2	1.207	1.208				
30" more in vapor of aniline at 185°.	17.8	78.8	2.605	2.603	5.50	—0.0125	24.15	19
	17.9	65.2	2.115	2.108				
	17.9	55.5	1.726	1.720				
	17.9	44.7	1.259	1.262				
1" more in vapor of aniline at 185°.	17.9	72.0	2.447	2.461	5.50	—0.0106	23.58	18
	17.9	64.7	2.178	2.163				
	17.9	53.8	1.703	1.696				
	17.9	46.5	1.374	1.371				
1" more in vapor of aniline at 185°.	19.2	68.8	2.327	2.325	5.74	—0.0114	23.12	18
	19.3	58.0	1.880	1.876				
	19.2	52.6	1.632	1.641				
	19.3	44.7	1.273	1.269				

BEHAVIOR OF HARD STEEL ANNEALED IN MOLTEN LEAD (330°).

From an inspection of the foregoing families of curves it appeared probable, in view of this relatively high temperature, that annealing effects of great magnitude would occur during the first minutes of exposure. Conformably herewith, the rods were subjected to 330° during consecutive intervals of 1^m, 30^m, and 1^h, and examined at the end of each of these times. The rods selected were:

No. 37; diameter (2ρ)=0.0820 cm.

No. 38; diameter (2ρ)=0.0616 cm.

No. 39; diameter (2ρ)=0.0483 cm.

The following results were obtained:

TABLE 25.—*Hard steel annealed at 330°.*[Rod No. 37. $2\rho=0.0820$.]

Remarks.	<i>t</i>	<i>T</i>	$\epsilon: 10^3$ observed.	$\epsilon: 10^3$ calculated.	<i>a</i>	<i>b</i>	s_1	<i>t</i>
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{\text{cm}}{\text{cm}^2} t$ microhm.	°C.
Glass-hard	18.7	53.1	-0.248	-0.248	0.00	-0.0089	38.51	18
	18.8	52.7	-0.215	-0.215				
	18.8	51.8	-0.206	-0.206				
	18.8	51.8	-0.206	-0.206				
1 ^m in molten lead at 330°.	17.8	77.5	3.898	3.898	7.74	-0.0126	18.96	18
	17.8	67.5	3.808	3.808				
	17.8	59.2	2.800	2.799				
	17.8	46.9	2.012	2.012				
30 ^m more in molten lead at 330°.	18.5	86.7	4.491	4.491	7.77	-0.0113	18.78	19
	18.5	75.2	3.806	3.808				
	18.5	62.3	3.003	3.005				
	18.5	50.7	2.252	2.251				
1 ^h more in molten lead at 330°.	18.9	69.0	3.471	3.458	7.71	-0.008	18.78	19
	18.9	57.2	2.667	2.685				
	18.9	47.6	2.045	2.038				
	18.9	39.4	1.472	1.470				

TABLE 26.—*Hard steel annealed at 330°.*[Rod No. 38. $2\rho=0.0616$.]

Remarks.	<i>t</i>	<i>T</i>	$\epsilon: 10^3$ observed.	$\epsilon: 10^3$ calculated.	<i>a</i>	<i>b</i>	s_1	<i>t</i>
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{\text{cm}}{\text{cm}^2} t$ microhm.	°C.
Glass-hard	18.8	50.2	-0.577	-0.573	-1.19	-0.0093	40.88	18
	18.8	44.8	-0.459	-0.461				
	18.8	39.6	-0.357	-0.360				
	18.8	34.8	-0.271	-0.269				
1 ^m in molten lead at 330°.	17.6	67.6	4.012	4.015	8.96	-0.0111	17.55	18
	17.7	61.3	3.532	3.531				
	17.7	53.1	2.998	2.998				
	17.6	42.7	2.083	2.084				
30 ^m more in molten lead at 330°.	18.8	87.8	5.470	5.470	9.24	-0.0124	17.86	19
	18.9	78.4	4.413	4.417				
	18.9	63.7	3.794	3.784				
	18.9	50.3	2.631	2.633				
1 ^h more in molten lead at 330°.	19.1	84.4	5.204	5.201	9.39	-0.0136	17.27	19
	19.1	63.3	3.649	3.649				
	19.1	50.1	2.810	2.815				
	19.1	41.7	1.936	1.932				

TABLE 27.—*Hard steel annealed at 330°.*[Wire No. 89. $2\rho=0.0483$.]

Remarks.	t	T	$\epsilon:10^2$ observed.	$\epsilon:10^2$ calculated.	a	b	$\frac{cm}{cm^2} \frac{t}{microhm.}$	t
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.		°C.
Glass-hard.....	18.0	53.8	-0.254	-0.254	0.08	-0.0110	36.04	18
	18.1	50.7	-0.221	-0.221				
	18.1	48.1	-0.195	-0.194				
1" in molten lead at 330°.	17.5	58.6	2.647	2.646	7.61	-0.0114	18.90	18
	17.5	51.7	2.835	2.834				
	17.5	45.8	1.948	1.948				
	17.5	39.6	1.540	1.537				
30" more in molten lead at 330°.	19.1	85.6	4.372	4.372	7.76	-0.0113	18.11	19
	19.1	72.9	3.610	3.615				
	19.1	61.9	2.987	2.929				
	19.1	50.4	2.180	2.182				
1 ¹ more in molten lead at 330°.	19.0	82.5	4.218	4.217	7.80	-0.0115	18.02	19
	19.0	66.7	3.255	3.254				
	19.0	57.8	2.687	2.687				
	19.0	49.5	2.142	2.142				

GENERAL DISCUSSION OF THE RESULTS OF THIS ANNEALING.

Digest.—The results thus far given adequately exhibit the general physical character of the process of tempering. For the sake of clearness, and with a view of partially eliminating such discrepancies as are due to incidental errors, the three individual values of thermo-electric power and specific resistance for each of the temperatures of annealing will be combined and their mean chosen for discussion. We thus arrive at the following relations:

TABLE 28.—*Mean results:*I.—*For annealing in vapor of boiling methyl alcohol (66°).*

Time of annealing=	⁰ _a	¹ _a	² _a	³ _a
	-1.62	-1.07	-0.80	-0.60

II.—*For annealing in steam (100°).*

Time of annealing=	⁰ _a	¹ _a	¹ _a	¹ _a	² _a	³ _a
	-0.91	0.17	0.95	1.50	2.08	2.36

III.—*For annealing in vapor of boiling aniline (185°).*

Time of annealing=	⁰ _a	¹ _a	¹ _a	¹ _a	² _a	³ _a
	-0.95	4.19	4.71	5.00	5.18	5.40

IV.—*For annealing in molten lead (330°).*

Time of annealing=	⁰ _a	² _a	¹ _a	¹ _a
	-0.37	8.11	8.26	8.30

Deduction.—If these functionalities are constructed graphically, as has been done in Fig. 10 (time as abscissa, thermo-electric constant as ordi-

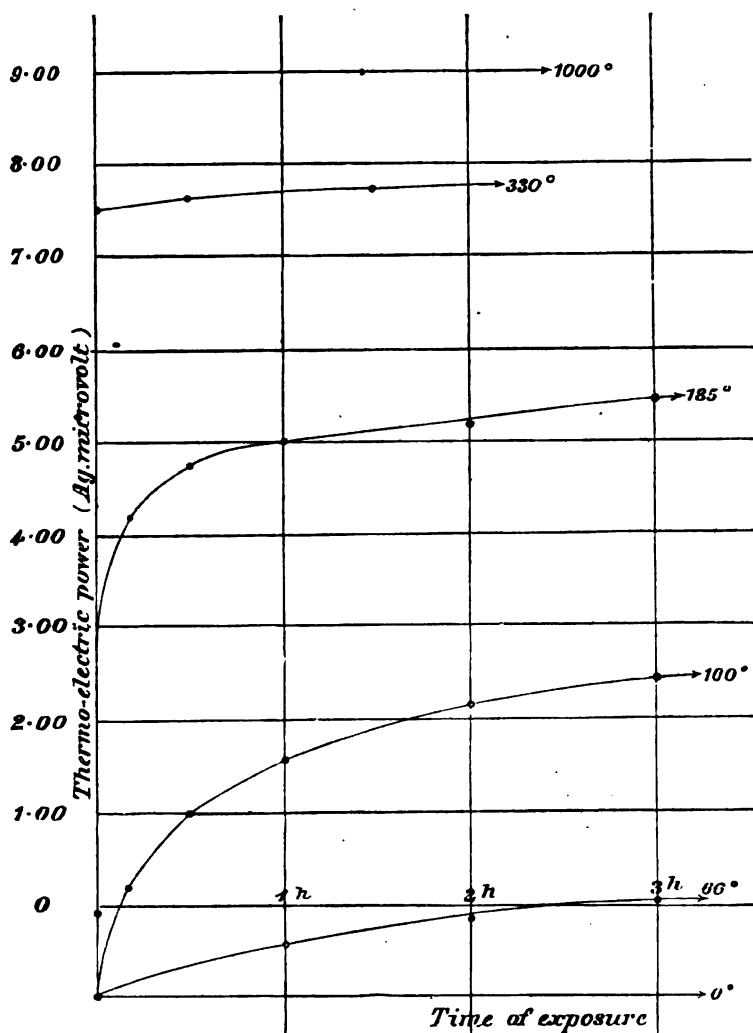


FIG. 10.—Hard wires annealed continuously at 0°, 66°, 100°, 185°, 330°, and 1,000°, respectively.

nate), we obtain a family of typical curves, the general character of which is distinctly pronounced and may be thus expressed:

The degree of hardness retained by a glass-hard rod, after having been subjected to the operation of annealing, is dependent both on the temperature to which it has been exposed and on the interval of time during which this exposure has taken place, in such a way that the effect of time, though of predominating importance in the case of small values of temperature, is more and more negligible in proportion as

these values increase. The operation is always most effective in its earlier stages, and this efficiency decreases very slowly where the temperatures are low—very rapidly, indeed almost suddenly, where they are high. If the action of any temperature be indefinitely prolonged, the rod under its influence ultimately reaches an inferior and limiting degree of hardness characteristic both of the temperature chosen and the type of steel under experiment. In other words: the annealing effect of any temperature increases gradually at a rate diminishing continuously through infinite time, very slowly in case of low temperature ($<100^{\circ}$), with extreme rapidity in case of high temperature ($>200^{\circ}$), so that the highest of the inferior states of hardness possible at any given temperature is approached asymptotically. The effect of the intensity of glass-hardness (strain) of the originally hard rod is not readily discernible.

The considerations set forth readily suggest the terminology: "*maximum of permanent hardness for the temperature t* "—an expression which will be used throughout the sequel to designate the highest of the inferior states of hardness, persistent at the said temperature, t .

The relatively large effect produced by low temperatures ($<100^{\circ}$), when a glass-hard rod is subjected to their influence for a long period of time, is deserving of special mention. It follows that a perceptible annealing effect must be attainable with temperatures much lower than the lowest above employed; indeed that the only inferior limit in this respect is probably the temperature of the water in which the rod was originally chilled,—while even the chilled rod, though kept at constant temperature, cannot be regarded as existing in a state of thorough molecular equilibrium until the lapse of a considerable interval of time after the hardening has taken place. Herefrom it appears that in the thermo-electric experiments the danger of destroying the uniformity of temper of a glass-hard rod by overheating the hot junction is greatly to be apprehended. Quick work and low temperatures are, therefore, to be preferred at an unavoidable sacrifice of accuracy. Nor is soldering of the ends permissible, except with the most extreme and intelligent caution. We desire to advert, in conclusion, to the important bearing of this unlooked-for sensitiveness of hard steel, even to low temperatures, on all other physical properties depending on the temper of this material—permanent magnetism for instance. It is obvious that the nature of a purely magnetic phenomenon can only be satisfactorily investigated when the material carrying the magnetic quality, throughout the course of the experiments undergoes no permanent change, otherwise we virtually commence our investigation with one rod and finish it with another, obtaining data which are not immediately, if at all, comparable.

ON THE EFFECT OF HIGHER AND OF LOWER TEMPERATURES ON THE TEMPER OF STEEL ORIGINALLY ANNEALED AT A GIVEN INTERMEDIATE TEMPERATURE.

Effect of lower temperatures.—The marked tendency of glass-hard rods to suffer diminution of hardness, even when exposed to temperatures but slightly above mean atmospheric temperature, naturally led to another important inquiry almost the converse of the preceding. We refer to the behavior of a rod annealed at a given temperature to the prolonged effect of lower temperatures subsequently applied.

For the purpose of obtaining experimental data a steel wire (No. 26, $2\rho=0.085$), which had on a former occasion been annealed in an oil bath at 250° , was exposed to steam at 100° for one hour. The results of the thermo-electric measurements made before and after this final exposure were these:

TABLE 29.—Steel annealed at t_3° exposed to t_1° , $t_2 > t_1$

Before.			After.			
t	T	$e: 10^2$	t	T	$e: 10^2$	$e: 10^2$
16.1	89.1	4.05	16.9	73.2	3.17	(3.22)
16.1	80.7	8.62	16.9	63.2	2.09	(2.72)
16.2	63.1	2.99	16.9	56.5	2.32	(2.35)
16.2	54.6	2.29	17.0	50.2	1.98	(1.99)
16.2	44.5	1.72				
16.2	37.9	1.84				

The temperatures t in both series are approximately identical. The electromotive force e may therefore be regarded as dependent on the difference of temperature $T-t$ only,³⁰ and with this presumption graphically represented. If, with the object of interpolating graphically, the two curves be carefully constructed, and the values of e for the temperatures of the one set of observations be derived from the curve for the other, then a comparison of corresponding values of e shows clearly that no annealing due to 100° is appreciable. In the table (29) the interpolated electromotive forces are distinguished by parentheses.

³⁰For $e=a(T-t)+b(T^2-t^2)=(T-t)(a+b[T-t]+2bt)=f(T-t)$ if t is constant.

This result was corroborated by a second experiment made in the same way with rod No. 27 ($2\rho=0.085$), which had been annealed in oil at 200° . The thermo-electric data obtained before and after the final annealing at 100° were:

TABLE 30.—Steel annealed at t_2° exposed to t_1° , $t_2 > t_1$.

Before.			After.			
t	T	$e:10^2$	t	T	$e:10^2$	$e:10^2$
16.3	88.5	2.62	17.0	84.2	2.45	(2.45)
16.4	80.8	2.38	17.0	71.7	2.08	(2.08)
16.4	70.0	2.06	17.1	62.3	1.76	(1.77)
16.4	61.6	1.77	17.2	43.4	1.09	(1.09)
16.4	53.1	1.48				
16.4	46.4	1.22				

Plainly these results admit of the following generalized interpretation: A steel rod, annealed at a given temperature, will remain the more nearly passive as regards the effect of an inferior temperature, the lower its value and the shorter its time of application on the one hand, and the nearer the mechanical state of the rod to the limit of hardness for the said temperature on the other. Where the limit in question has been fully reached the rod is unaffected by the action of lower temperature, however prolonged.

Effect of higher temperatures.—There is another question of a similarly important bearing on the nature of the phenomena of annealing. In the above we drew the general inference that in the case of a given rod possessing a given degree of glass-hardness, the mechanical state resulting after annealing is dependent on the temperature and the time of exposure only; that when the latter is indefinitely prolonged, a particular and characteristic limit of hardness is reached for each temperature of the annealing bath. If this be the case, then it must be immaterial, in so far as the identity of the final states is concerned, whether, for instance, a rod is first annealed in steam at 100° and then in aniline vapor at 185° to a limit, or whether it is annealed to a limit in aniline vapor at once. In other words, the maximum reduction of hardness attainable by the action of any given temperature on glass-hard steel is independent of the manner of variation of hardness (the path as it were) by which this final state is reached. On this point the following experiments were made:

Three steel wires of different thicknesses (Nos. 40, 41, 42), carefully tested for longitudinal homogeneity, were first examined in the glass-hard state. They were then broken in two, and one of the halves of each was annealed directly in aniline vapor at 185° for 10 minutes; the others, however, were first exposed in steam at 100° for 40 minutes, and after this, as in the former case, for 10 minutes in aniline. Hereupon the six rods were tested for hardness, with the following results. It

was expedient to make measurements of resistance only, Hockin and Matthiessen's method being employed:

In steam and in aniline vapor.		In aniline vapor only.	
Rod No. 40 ($2\rho=0.085$)	Glass-hard $s=41.8$	$s=40.6$	($t=14^{\circ}$)
	Annealed $s=31.0$	$s=30.6$	
Rod No. 41 ($2\rho=0.064$)	Glass-hard $s=43.0$	$s=42.9$	($t=14^{\circ}$)
	Annealed $s=30.0$	$s=29.8$	
Rod No. 42 ($2\rho=0.049$)	Glass-hard $s=36.4$	$s=36.5$	($t=14^{\circ}$)
	Annealed $s=26.0$	$s=26.0$	
Mean	Glass-hard $s=40.2$	$s=40.0$	($t=14^{\circ}$)
	Annealed $s=29.0$	$s=28.8$	

A second experiment was made with three other wires (Nos. 43, 44, 45). After the hardness for the glass-hard state had been obtained, the rods were again broken in two; one of the halves of each was annealed for 40 minutes in ethylic alcohol vapor at 78° , and then for 6 hours in steam; the others in steam only during the same interval. The results obtained are these:

In vapor of alcohol and in steam.		In steam only.	
Rod No. 43 ($2\rho=0.085$)	Glass-hard $s=40.2$	$s=40.6$	($t=10^{\circ}$)
	Annealed $s=31.9$	$s=31.8$	
Rod No. 44 ($2\rho=0.066$)	Glass-hard $s=40.5$	$s=41.2$	($t=10^{\circ}$)
	Annealed $s=29.4$	$s=29.8$	
Rod No. 45 ($2\rho=0.049$)	Glass-hard $s=33.5$	$s=35.8$	($t=10^{\circ}$)
	Annealed $s=27.5$	$s=27.9$	
Mean	Glass-hard $s=38.7$	$s=39.2$	($t=10^{\circ}$)
	Annealed $s=29.8$	$s=29.7$	

Both of these series of experiments are in perfect accord, and we therefore infer: The specific effect of a given temperature of annealing on the state of hardness of steel is independent of the possibly pre-existing effects of a lower temperature, to the extent that the result of the influence of the latter is the more fully annulled the greater the period of action of the former.

Anomalous feature.—This result is remarkable, inasmuch as by a sudden exposure of a glass-hard rod to (high) temperature, a very large amount of potential energy is *instantaneously* released. If, therefore, two identical glass-hard wires be annealed, the one by raising the temperature very gradually as far as t° , the other by being suddenly exposed to t° , we would infer, *ceteris paribus*, that a difference of hardness must result. For, in view of the sudden conversion of the available mechanical energy into heat in the latter case, we anticipate an equivalent increase in the temperature of the rod. Virtually, therefore, this steel is annealed at a temperature somewhat above that of the annealing bath, or above that of the other rod. So far as our experiments went this was not detected; but the test made is not exhaustive. Our attention was centered on other matters at the time. Possibly, however, the anomalous distribution of hardness obtained by annealing in oil may be partially accounted for in this way.

BEHAVIOR OF SOFT STEEL RODS.

Object of the measurement.—The above values for thermo-electric power all refer to elements in which steel is thermo-electrically combined with pure soft silver; but the latter metal, though chosen expediently, is otherwise arbitrary and without inherent bearing on the subject in hand. We will undoubtedly obtain data more in harmony with the purpose of the present investigation, and far more readily intelligible, by eliminating this foreign metal from our considerations entirely. It is to be our endeavor throughout the following paragraphs not only to add to the perspicuity of our data, but also to give them possibly immediate theoretical significance, by referring all measurements to a particular and normal state of steel. The soft state would appear to suggest itself in so far as it occupies an extreme and inferior position in the scale. If, however, this is to be chosen as a point of departure, the rods in this state should possess normal and fixed thermo-electric qualities, even for different kinds of steel. This is by no means the case, as the special experiments presently to be detailed will show. Indeed, even in the case of soft rods nominally of the same material, at all events nearly of identical composition, the difference of thermo-electric power is often very marked.

Method of softening.—With the object of reaching extreme values of the soft state, the rods were embedded in artificial powdered ferro-ferric oxide, as it falls from the anvil, and surrounded by a closed gas-pipe; the latter in turn enveloped in a thick coating of fire-clay, protected externally with thin sheet-iron. The whole was heated to intense redness, and then allowed to cool very slowly in the ashes of the smoldering fire³¹. The non-conducting envelopes insured a very gradual subsidence of temperature.

Data for soft steel and for soft iron.—As examples the results obtained with rods Nos. 46, 47, and 48 will be given:

TABLE 31.—Behavior of soft steel rods.

Remarks.	t	T	e observed.	e calculated.	a	b	s	t
	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{\text{cm}}{\text{ohm}^2}$	$^{\circ}\text{C.}$
No. 46. $2\rho=0.0843$	18.7	87.7	486.8	486.2	8.33	-0.0121	17.08	19
	18.7	87.8	354.8	354.5				
	18.7	54.2	264.0	264.6				
	18.7	45.5	202.8	202.6				
No. 47. $2\rho=0.0625$	23.0	85.7	543.5	544.8	10.17	-0.0137	15.09	19
	22.7	63.1	406.9	405.5				
	22.6	51.7	266.9	266.4				
	22.4	40.6	169.0	169.3				
No. 48. $2\rho=0.0485$	19.0	84.0	474.7	472.5	8.52	-0.0121	16.41	19
	19.0	64.3	338.4	340.1				
	19.0	50.8	242.6	243.9				
	19.0	37.9	148.9	148.0				

³¹ With regard to the decarbonization possible or incident to this operation see Chapter III.

For the sake of comparison iron wires of different kinds were treated in the same way and subsequently examined. The results obtained with Nos. I, II, and III will be cited as examples:

TABLE 32.—*Behavior of soft iron wire.*

Remarks.	t	T	ϵ observed.	ϵ calculated.	a	b	s	t
	°C.	°C.	microvolt.	microvolt.	microvolt.	microvolt.	$\frac{\text{cm}}{\text{cm}^2}$ microhm.	°C.
No. I. $2\rho=0.0906$	18.7	79.6	581.3	582.0	11.25	-0.0174	13.02	19
	18.8	66.3	465.4	464.9				
	18.7	54.3	356.3	355.8				
	18.8	44.9	264.7	265.0				
No. II. $2\rho=0.0630$	18.6	78.0	550.2	549.5	10.56	-0.0135	12.74	19
	18.6	64.2	430.1	430.3				
	18.6	53.4	332.6	333.6				
	18.6	43.4	241.6	241.1				
No. III. $2\rho=0.0312$	18.5	86.9	560.2	560.0	9.66	-0.0140	13.87	19
	18.5	68.1	418.0	419.1				
	18.5	54.3	310.3	309.3				
	18.5	40.1	190.7	190.9				

Impurities in steel and iron.—Now, there is reason to suppose that in the case of iron carburets generally the electrical effect of foreign impurities is partially masked by the phenomenally great effect of combined carbon.³² Conformably with the usually accepted views, therefore, the shifting of thermo-electric position due to the presence in iron of materials (S., P., Si., etc.) other than carbon will be particularly marked for the soft states. For it is here that the quantity of combined carbon contained is at a minimum, while the steel itself is in a natural homogeneous state. We have analogies in the case of alloys. For instance, on alloys of gold and silver small additional quantities of foreign admixtures are relatively without marked electrical effect, whereas if pure gold or pure silver be adulterated with the same quantities of the same material the result is pronounced. If we compare the values of a and s for soft iron with those obtained for soft steel the specific effect of carbon is strikingly obscure. We are induced to refer the comparatively small differences apparent to the effect of foreign impurities in the iron. At least, in contrast with the phenomenal electrical interval between the glass-hard and the soft states of steel, the electrical effect of carbon is here wholly masked by that of the incidental ingredients. But it is herewith fully demonstrated that the steel rod possessing the qualities of a normal must be sought for elsewhere than in the soft state.

³²Directly or indirectly. It will be shown in the sequel that the electrical variation discussed in this chapter is probably due to the strain accompanying hardness, but this in its turn is conditioned by the presence of carbon in iron.

THE RELATION EXISTING BETWEEN THE THERMO-ELECTRIC POWER
AND THE SPECIFIC RESISTANCE OF STEEL.

Reduction of data.—In the above experiments we have thus far met with 86 pairs of correlative values of specific resistance and thermo-electric constant. We will supplement these results by values obtained with four rods subjected to six hours of annealing in steam. They are as follows:

Rod.	2ρ	a	s_t	t
No. 49	0.0574	1.90	35.75	19
No. 50	0.0554	4.08	29.34	19
No. 51	0.0531	4.06	27.08	19
No. 52	0.0344	3.90	28.68	19

In all, therefore, we are in possession of 90 pairs of values. These amply suffice to decide in how far an intrinsic relation between thermo-electric power and specific resistance, in case of one and the same metal (steel), in different states of temper, demonstrably exists. Now we have

$$\left(\frac{d\theta}{d(T-t)} \right)_{-T=t} = a;$$

whence it appears that the thermo-electric constant a primarily refers to the temperature zero, centigrade. It is, therefore, consistent to reduce the observed values of specific resistance (18° — 21°) to the same temperature (zero). This is at best a laborious piece of work, and moreover presupposes a knowledge of the relation of resistance and temperature (the coefficients vary within the large range of 0.1 per cent. nearly to above 0.4 per cent.) for each of the 90 degrees of hardness encountered. But with the aid of the results contained in Chapter I of the present memoir this reduction may be satisfactorily made. The results are given in the following table, where $s_t = s(1 + \alpha t)$:

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TABLE 33.—Specific resistance (cm/cm² 0° microhm) of steel.

No.	s_t	t	$a \times 10^8$	s	No.	s_t	t	$a \times 10^8$	s	No.	s_t	t	$a \times 10^8$	s
1	18.96	19	3.4	17.81	29	41.32	19	1.7	40.03	35	28.58	20	2.4	27.27
2	18.49	19	3.5	17.34	30	37.08	18	1.8	35.92	35	27.26	19	2.5	26.03
3	20.54	19	3.1	19.40	30	36.80	18	1.9	35.58	35	26.04	19	2.6	24.81
4	20.00	19	3.3	18.22	30	36.51	18	1.9	35.30	35	25.29	18	2.7	24.11
5	17.64	19	8.6	16.51	30	36.42	19	1.9	35.15	35	24.72	18	2.7	23.37
6	20.75	20	3.2	19.51	31	40.47	21	1.7	39.08	36	37.17	21	1.8	35.82
7	22.74	19	2.9	21.55	31	39.05	20	1.8	37.70	36	25.85	20	2.6	24.58
8	23.20	19	2.9	21.99	31	37.64	19	1.8	36.40	36	24.91	19	2.7	23.69
9	20.47	19	3.2	19.30	31	36.33	19	1.9	35.06	36	24.15	19	2.8	22.93
10	25.67	19	2.6	24.46	31	35.58	18	1.9	34.21	36	23.58	18	2.9	22.41
11	24.81	19	2.7	23.60	31	34.72	18	2.0	33.50	36	21.12	18	2.9	21.97
12	22.93	19	2.9	21.73	32	41.42	21	1.7	39.99	37	36.51	18	1.9	35.30
13	20.66	19	3.2	19.48	32	39.53	20	1.7	38.23	37	18.96	18	3.4	17.87
14	27.36	20	2.6	26.06	32	38.02	19	1.8	36.76	37	18.78	19	3.4	17.64
15	28.11	19	2.4	26.88	32	36.33	19	1.9	35.06	37	18.78	19	3.4	17.64
16	26.70	19	3.5	25.49	32	35.19	18	1.9	34.03	38	40.38	18	1.7	39.17
17	27.93	19	2.4	26.71	32	34.34	18	2.0	33.14	38	17.55	18	3.6	16.48
18	31.32	19	2.3	30.06	33	36.98	21	1.8	35.64	38	17.36	19	3.6	16.25
19	28.68	19	2.4	27.48	33	35.06	20	1.9	33.72	38	17.25	19	3.6	16.16
20	24.34	19	2.8	23.11	33	33.58	19	2.0	32.85	39	36.04	18	1.9	34.85
21	29.34	19	2.3	28.11	33	32.26	19	2.1	31.02	39	18.30	18	3.5	17.22
22	30.94	19	2.2	29.70	33	31.22	18	2.2	30.03	39	18.11	19	3.5	16.98
23	27.93	19	2.4	26.71	33	30.67	18	2.2	29.49	39	18.02	19	3.5	16.89
24	42.64	18	1.6	41.45	34	39.34	21	1.7	37.98	46	17.08	19	3.6	15.98
25	42.55	18	1.6	41.36	34	39.25	20	2.3	27.96	47	15.09	19	3.9	14.05
26	42.45	19	1.6	41.20	34	28.02	19	2.4	26.80	48	16.41	19	3.7	15.34
27	42.55	19	1.6	41.30	34	27.17	19	2.5	25.94	49	35.75	19	1.9	34.51
28	42.08	17	1.6	40.05	34	26.32	18	2.6	25.14	50	29.34	19	2.3	28.11
29	41.70	18	1.6	40.53	34	25.85	18	2.6	24.69	51	27.08	19	2.5	25.85
30	41.52	19	1.7	40.12	35	42.45	21	1.6	41.07	52	28.68	19	2.4	27.48

Fundamental constants.—For the sake of greater clearness in designation, let a be replaced by y' , s_0 by x . Parallel variations of y' and x we have had frequent occasion to notice. But we have now the data in hand for a complete discussion of the nature of their mutual dependence, and this will manifest itself perspicuously and at once in a graphic representation with x as abscissa, y' as ordinate. Figure 11 contains the 90 points in question. They lie within a band or pathway which, as a rule, is narrow, especially so near its middle, but widens somewhat as we approach the lower extremity, where $y'=0$. Nevertheless, the character of the functionality involved within the given range of possible variation appears with due prominence. *It is unquestionably linear.*

We may, therefore, with great probability premise that between y' and x a relation of the form

$$y' = m - nx \quad (1)$$

exists. If we make this equation the basis of a calculation in which the fundamental constants m and n are to be determined by the method of least squares we arrive at the values

$$m = 15.176$$

$$n = 0.4123$$

by solving the normal equations

$$P = mA - nB$$

$$Q = mB - nC$$

where

$$A = \sum X^0 = 90$$

$$B = \sum X = 2536.55$$

$$C = \sum X^2 = 773.21$$

$$P = \sum y' = 319.91$$

$$Q = \sum Xy' = 6612.1.$$

New thermo-electric data.—Of these constants, m commands only secondary interest, in so far as it depends on the metal (silver in our case)

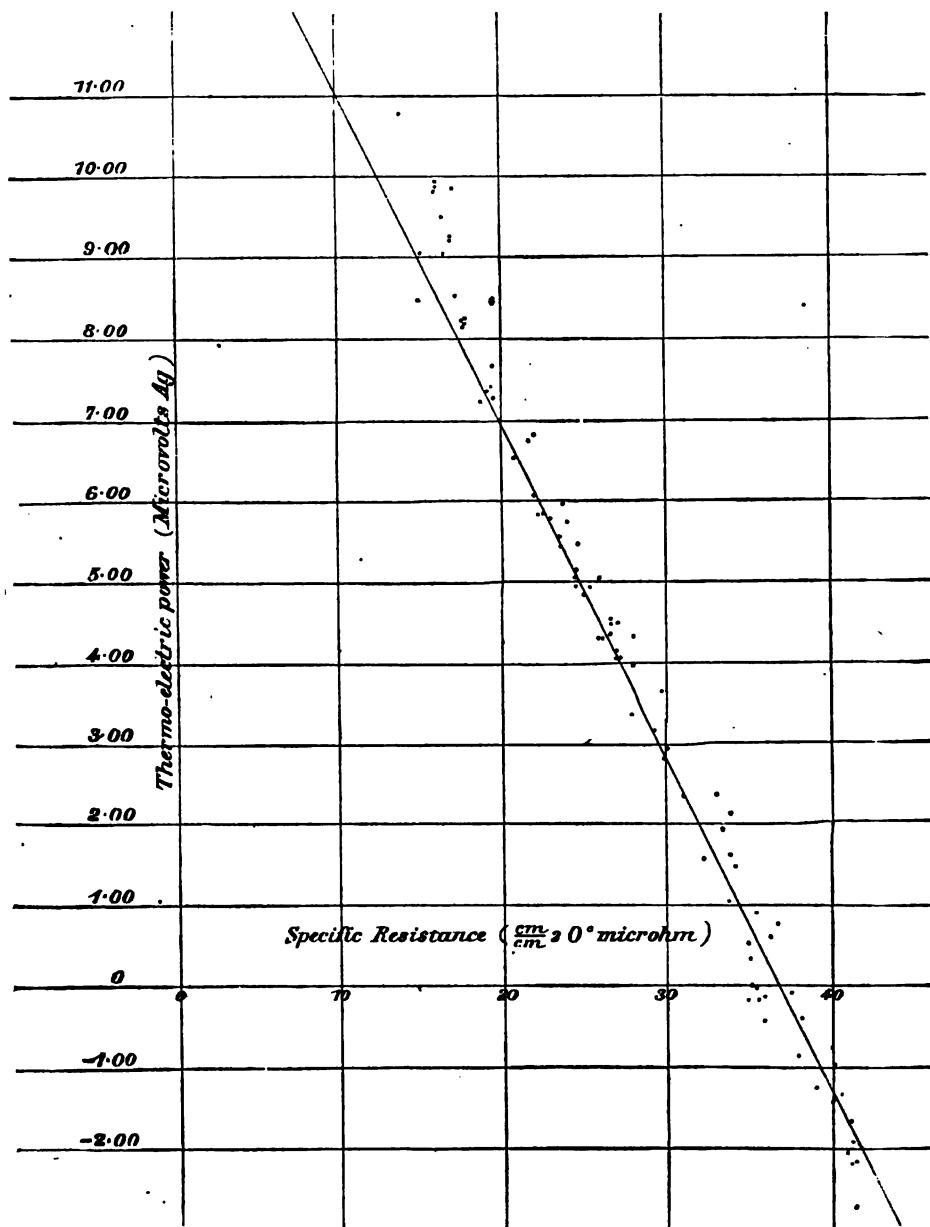


FIG. 11.—Diagram of the relation between the thermo-electric power of steel in different states of temper, and its specific resistance.

arbitrarily chosen to fix a datum or point of departure for thermo-electric measurements. This, however, is not true of $m-y'$, a quantity wholly

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independent of the arbitrary element in question. It therefore appears expedient to select $m-y'=h$ as a new thermo-electric variable, in which case (1) reduces to the simpler form $h=nx$. The new thermo-electric data (h, nx) thus obtained are exclusively dependent on qualities inherent in steel. They have no reference to metals (silver) foreign to the present purpose. From a mathematical standpoint m is the experimental constant by which a specially selected set of co-ordinates is determined. From a physical standpoint m would represent the thermo-electric constant of a couple, one member of which is silver, the other the imaginary steel rod, whose specific resistance, supposed diminishable indefinitely in accordance with the above law, is zero. It is this initial state of hardness ($h=0$) at which the new variable h originates.

Thermo-electric hardness defined.—The new thermo-electric variable, h , will, throughout the present memoir, be designated by the term *thermo-electric hardness*. The introduction of this quantity was suggested, to us by considerations similar to those which led to the conception of absolute temperature. To the absolute zero of temperature, however, Thomson has been able to give a concrete physical interpretation; whereas the zero of thermo-electric hardness, so far as the results of the present chapter go, furnishes no more than a point of departure, at once convenient and free from arbitrary assumptions. It is hardly necessary to cite as a second example the hypothesis defining the modulus of elasticity, for instance.

The following is a brief summary of the advantages immediately derived from the introduction of thermo-electric hardness:

1. Hardness in the case of steel is expressed for the soft as well as for the hard rod in significant and at the same time convenient figures, which increase as this quality increases. The scale is, therefore, adapted to circumstances.

2. A change of signs is avoided, the current invariably flowing from the given specimen through hot to the normal. In other words, the normal is thermo-electrically positive to the whole family of iron-carburets, iron, steel and cast iron, no matter what be their mechanical state.

3. The results are independent of the shiftings of thermo-electric position common to all metals, due to small amounts of impurity or difference of mechanical state.

4. By the aid of the coefficients discussed in chapter I and for the sake of concreteness of conception only, we may state that, theoretically, the normal condition of steel, to which thermo-electric hardness refers, would nearly be given by soft steel cooled down as far as the absolute zero of temperature. (See Chapter III.)

Tabular comparisons.—A complete table follows, showing the differences between observed ($h=m-y'$) and calculated (nx) values of thermo-

electric hardness. As has been stated, the results are deduced by the method of least squares :

TABLE²¹ 34.—Comparison of the values of the thermo-electric hardness and specific resistance.

No.	h	nz	Diff.	No.	h	nz	Diff.	No.	h	nz	Diff.
1	7.38	7.34	0.04	29	15.88	16.50	-0.62	35	10.96	11.24	-0.28
2	7.15	7.15	0.00	30	15.60	14.81	0.79	35	10.43	10.73	-0.30
3	8.19	8.00	0.19	30	15.19	14.67	0.52	35	10.00	10.28	-0.28
4	7.40	7.76	-0.36	30	14.88	14.56	0.32	35	9.76	9.94	-0.18
5	6.66	6.81	-0.15	30	14.71	14.49	0.22	35	9.54	9.72	-0.18
6	7.94	8.04	-0.10	31	16.38	16.11	0.27	36	15.23	14.77	0.46
7	9.03	8.88	0.15	31	15.26	15.54	-0.28	36	10.42	10.18	0.29
8	8.73	9.07	-0.35	31	14.63	15.01	-0.38	36	9.92	9.77	0.15
9	8.22	7.96	0.26	31	14.32	14.45	-0.13	36	9.68	9.45	0.23
10	10.51	10.08	0.43	31	13.63	14.10	-0.47	36	9.68	9.24	0.44
11	10.03	9.73	0.30	31	13.37	13.82	-0.45	36	9.44	9.06	0.38
12	8.78	8.96	-0.18	32	16.62	16.49	0.13	37	15.18	14.56	0.62
13	8.29	8.08	0.26	32	15.57	15.76	-0.19	37	7.44	7.37	0.07
14	11.12	10.74	0.38	32	14.38	15.16	0.78	37	7.41	7.27	0.14
15	11.33	11.08	0.25	32	13.79	14.45	-0.66	37	7.47	7.27	0.20
16	10.51	10.51	0.00	32	13.17	14.03	-0.86	38	16.37	16.15	0.22
17	10.92	11.01	-0.09	32	12.92	13.66	-0.74	38	6.22	6.79	-0.57
18	12.89	12.39	0.50	33	15.25	14.69	0.56	38	5.94	6.70	-0.76
19	11.85	11.31	0.54	33	14.21	13.90	0.31	38	5.79	6.66	-0.87
20	9.78	9.58	0.20	33	13.68	13.34	0.34	39	15.10	14.37	0.73
21	11.42	11.59	-0.17	33	12.93	12.79	0.14	39	7.57	7.10	0.47
22	11.77	12.25	-0.48	33	12.51	12.38	0.13	39	7.42	7.00	0.42
23	10.94	11.01	-0.07	33	12.18	12.16	0.02	39	7.38	6.97	0.41
24	17.74	17.09	0.65	34	16.01	15.66	0.35	46	6.85	6.59	0.26
25	17.12	17.05	0.07	34	11.59	11.53	0.06	47	5.01	5.79	-0.78
26	16.99	16.99	0.00	34	11.08	11.05	0.03	48	6.66	6.32	0.34
27	16.76	17.08	-0.27	34	10.85	10.69	0.16	49	13.28	14.23	-0.95
28	17.08	16.89	0.19	34	10.57	10.37	0.20	50	11.10	11.69	-0.49
29	16.43	16.71	-0.28	34	10.34	10.18	0.16	51	11.12	10.66	0.46
30	16.09	16.54	-0.45	35	17.15	16.93	0.22	52	11.28	11.31	-0.03

²¹ The second decimal place (h , nz , diff.) serves only, of course, to give greater accuracy to the first and might perhaps have been advantageously suppressed.

Distribution of errors.—If this series of results is examined critically, that is with especial reference to magnitude and location of the errors, relatively large discrepancies encountered at the beginning of the table, in the case of very soft rods, are conspicuous. It is not, therefore, to be considered as finally decided whether the relation $h=f(x)$ may not for small values of x be other than linear; such, however, as rapidly to approximate to the latter form of function as x increases. The other errors in general are as liable to assume positive as negative values; they lie within sufficiently narrow limits, and do not, with one exception, exhibit any characteristic progress for consecutive states. In the case of wires annealed in methyl alcohol a uniform succession of errors is, however, apparent. For continually decreasing values of h we have:

No. 28.....	7	1	0	-3
No. 29.....	2	-3	-5	-6
No. 30.....	8	5	3	2

In other words, with continually augmenting time of exposure, the temperature, 66°, produces an annealing effect such that the linear relation between thermo-electric hardness and specific resistance is not rigidly maintained. Here we have unquestionably the evidences of a

structural phenomenon. The inference is plausible that the annealing influence of this comparatively low temperature is largely confined to those parts of the rod where the strain is most intense. This is probably the case with the superficial layers; for, according to Fromme's datum the density of these has been increased enormously. Now, it would seem that it is upon the surface layers of a rod that thermo-electric power is principally dependent, whereas specific resistance varies with the mean hardness of rod taken as a whole. The discrepancy in question is repeated with such uniformity in each of the three wires, that it is obvious we have in hand more than a mere error of observation. Furthermore, the similar variation which occurs in the case of wires annealed at 100° shows that the anomaly exists in steel itself, and is deserving of special inquiry.

Consequences of an elementary law, $h=ns$.—A more detailed analysis of the thermo-electric effects of structure does not substantiate the stated inference that the thermo-electric data are influenced to a greater extent by the condition of the surface layers of steel than the resistance data.

From the very general evidence obtained in Table 34 in favor of the law $h=ns$, we are justified in giving it fundamental or elementary importance. In other words, the supposition is warranted that, for each of the coaxial necessarily homogeneous elementary shells of which we may suppose the rod to be made up, the relation

$$h=ns \quad \dots \dots \dots (1)$$

applies. Suppose, now, we take into consideration any two such shells.

Let $s_1, s_2, h_1, h_2, q_1, q_2$, be their specific resistances, their thermo-electric hardness, and their right sections, respectively.

Let $s_{12}, h_{12}, q_{12}=q_1+q_2$, be the specific resistance, thermo-electric hardness, and right sections, respectively, of a single shell, which is capable galvanically and thermo-electrically to replace the two original shells (they are actually combined in multiple arc) in every respect. Then

$$h_{12} = \frac{h_2 \frac{s_1}{q_1} + h_1 \frac{s_2}{q_2}}{\frac{s_1}{q_1} + \frac{s_2}{q_2}} \quad \dots \dots \dots (2)$$

and

$$s_{12} = \frac{\frac{s_1}{q_1} \frac{s_2}{q_2}}{\frac{s_1}{q_1} + \frac{s_2}{q_2}} q_{12} \quad \dots \dots \dots (3)$$

It therefore follows, in view of equation (1), that

$$h_{12} = \frac{n}{q_{12}} (q_1 + q_2) s_{12} = n s_{12}$$

and in the same way generally

$$h_{1, 2, 3} \dots = \frac{n}{q_{1, 2, 3}} \Sigma (q_k) s_{1, 2, 3} \dots = n s_{1, 2, 3} \dots$$

That is, if the law $h=ns$ be true for the elementary (necessarily homo-

geneous) layers of the rod, then must it be true also for the rod taken as a whole, however complicated its structure may be, and whatever be the difference in the variation of the density of successive layers while annealing is in progress. The converse of this does not follow so readily.

The superficial layers of the steel, being the ones directly and immediately operated upon in sudden cooling, will probably be the ones experiencing greatest intensity of strain. It may be plausibly argued, therefore, that the effect of incipient annealing is confined to these, or at least that the said layers expand at a far more rapid rate than the rod as a whole contracts. The law $h=ns$ may therefore be considered to apply with good approximation, both in the case of volume expansion and of volume contraction.

We may account for the progressive errors encountered in the case of hard wires annealed at low temperatures ($<100^\circ$) from two points of view: Either the elementary law $h=ns$ is not *rigidly* true throughout the phenomenal variation of density which the individual layers experience on tempering (probably from 7 to 10); in other words, $h=f(s)$ is no longer rigidly linear when we approach the enormous condensation near the surface, for instance. Or, the discrepancy may be due to the facts observed by Caron³² that a hard-steel rod during the annealing contracts *æolotropically*; i. e., not in like ratio both in the direction of its longitudinal and its radial axes. In such a case the law $h=ns$, conceded rigidly to hold good for isotropic strains, need no longer do so in the case in hand. This discussion will be advantageously resumed, in the light gained from further relevant data, in chapter III.³³

SOURCES OF ERROR.

The difference between the observed and the calculated results of thermo-electric hardness, as exhibited in the last paragraph, pertinently suggest an especial inquiry in regard to how far they are referable to errors of observation. This involves an examination into the possible discrepancies incident to the various methods of measurement used.

Thermo-electric measurement.—If we commence with the thermo-electric measurement we at once encounter a series of obvious sources of error which may be thus classified: Variation of the factor of reduction of the galvanometer, to be referred in part to fluctuations in the intensity of terrestrial magnetism, in part to the immediate influences due to changes of atmospheric temperature; the inconstancy of the electromotive force of the Daniell between the observations made for the determinations of the same; the effect of extraneous thermo-currents in

³² Caron : Comptes rendus, LVI, p. 211, 1863.

³³ Chapter III, p. 88.

the galvanic connections; and, finally, the difficulties surrounding an accurate measurement of the temperatures of the thermo-electric junctions, especially when they are high. The first two of these may be satisfactorily avoided by frequent repetitions of a series of systematic and corroborative measurements. The devices²⁴ by which we endeavored to eliminate the third have already been fully described; nevertheless the distortion due to this cause is not thoroughly eliminable, and its effect will be most apparent in the case of small values of thermo-electric force. Steel wires lying very near pure silver in the thermo-electric scale are therefore apt to be seriously influenced. Conformably herewith, the column of "differences" in the foregoing table (34) shows large values when y' is approximately zero. But there is another reason for these relatively large discrepancies, which deserves mention as being even of more importance than the one just referred to. The thermo-electromotive force is expressed by the aid of two constants, thus—

$$e = a(T - t) + b(T - t^2)$$

whence it follows that the accuracy of the constant a , resulting from the calculation, is conditioned to some extent by the accuracy of b ; for, although the latter is usually small relatively to the former, it enters the equation

$$e = [a + b(T + t)](T - t)$$

as a co-efficient of the sum of the temperatures T and t . Now, an accurate measurement of b presupposes a large range of variation of the difference of temperatures T and t ; and it is just here that in the case of glass-hard rods we encounter an unavoidable difficulty. Large values of T are inadmissible, because they change the temper of the exposed junction of the rod. It is equally inexpedient to cool t below zero. At least our attempts in this direction served only to convince us that the errors encountered in consequence of insufficient constancy of t more than counterbalance the advantages gained, to say nothing of annoyances of a practical kind. An inspection of some of the earlier tables will show that wherever the value of a is larger or smaller than was with good reason to be anticipated, this discrepancy is compensated by a similar error of b . Indeed the calculations from which the constants of the 90 series of experiments given above were derived, clearly show that a number of observations greater than four for each value of a is indispensable for an advantageous application of the method of least squares. This did not urgently appeal to us until the measurements were well in progress, and we were equally undesirous both of changing the routine adopted and of encountering additional labor in the calculations. Four observations, however, will not suffice where an accuracy of a within one per cent. is demanded. We also observed that

²⁴ Cf. pp. 34-35.

the correlative values of a and b were materially different, according as the equation

$$y = ax + bxu$$

or

$$\frac{y}{x} = a + bu$$

was assumed for the application of the method of least squares.

Resistance measurement.—The values for specific resistance are liable to two sources of error. The first of these, which is due to variations of temperature, the results contained in Chapter 1 have enabled us largely to eliminate. The second error is of a more serious kind, and embraces the difficulties encountered in endeavoring to obtain values for the sections of (thin) rods. As the average thickness of our wires was only about 0.05 centimeter, it would have been necessary to measure the mean diameter to $\frac{1}{1000}$ centimeter in order to arrive at a mean section correct to within one per cent. This is not feasible, except with extreme precautions, either by the use of microscopic or gravimetric methods. In the case of thinner wires the difficulty is proportionately increased. Such errors as are due to imperfections of contact at the places of insertion of steel wires, etc., have been already touched upon.³⁵ They were wholly avoided eventually by a change of method.

Other errors.—In addition to the sources of errors just mentioned, such as are more intrinsically connected with the subject discussed, deserve consideration. It has been stated that the inference is warranted that the rods used were not quite identical as regards chemical composition, and that the electrical behavior of these, though alike in kind, may differ in degree.

CONCLUDING REMARKS.

A brief review of the general tenor of the results discussed in the above, in so far as they have a bearing on certain important consequences which we desire now to touch upon, will be in place here. We purposely avoid all remote theoretical speculations and confine ourselves to inferences immediately deducible from the facts.

Tempering.—The physics of the process of tempering have thus far been but slightly understood; and it is therefore to the new light which the present chapter throws upon the essential features and results of this operation that we desire first to advert. Only cursory attention³⁶ has hitherto been given to the phenomenal difference between

³⁵ Cf. pp. 37–38.

³⁶ In certain thermo-electric measurements incidentally made by Joule (Phil. Trans., 1859, I, pp. 95–97). The results for variation of specific resistance of all earlier observers (Mousson, Chwolson) are erroneously small.

the extremes of mechanical state: the glass hard and the soft. The largest thermo-electric interval observed in the present work is $10.17 - (-2.60) = 12.8$; and the maximum ratio of the respective values of specific resistance, $\frac{1}{3} = 3.0$. It is this enormous range of variation of the electrical properties, together with the facility with which *absolute* data dependent merely on qualities essentially inherent in steel are obtainable, that would seem emphatically to recommend the scale of hardness here introduced to the attention of physicists. Furthermore, the method of annealing adopted enables the observer to carry the temper from any given initial state to any desirable final state within the range of possible variation in a safe and systematic way. Of the two factors which condition the degree of hardness reached—the temperature of the annealing bath and the time of exposure of the hard steel rod—the latter if sufficiently prolonged is particularly effective for very small values of the former. If annealing be continued through infinite time, the ultimate states (measured as thermo-electric hardness), would appear to decrease continuously as the temperature increases, though there is reason to predict the existence of a minimum between 400° and 600° . We had commenced a special investigation of this functionality, but the work was forcibly interrupted. It is still to be noted that the maximum annealing effect of a temperature t' is independent of the possibly pre-existing effects of a temperature t , and is not in any way influenced by subsequent applications of the latter, provided $t' > t$.

Scheme for magnetic and other allied researches.—The results above detailed open up a large field for further research in directions differing from those of the present chapter. Indeed, wherever we have to deal with those properties which depend essentially on the hardness of steel, the experiments discussed in the above formally prescribe, as it were, a method of procedure at once expedient and safe.

From a physical point of view, steel possesses a special and peculiar interest in virtue of its pronounced magnetic properties. The importance of the influence of hardness on the intensity of permanent magnetization has long been known. But the confusion and discordance in the results of all observers bear witness to the difficulties encountered, not only from the vagueness which attaches to the term steel, but principally out of the want of a method by which identical mechanical states can be rigidly defined. As a consequence the data of many laborious researches do not readily admit of direct comparison, and are therefore nearly valueless. Indeed, we may add that even in the case of one and the same type of steel each rod must be regarded as an individual.

It follows, therefore, that a plan of research in which a given steel rod is carried, by annealing, from an initial hard to a final soft state, through all intermediate states, is alone adapted to the class of experiments under discussion. And here again the peculiar mechanical condition

which we have above characterized as the limit of hardness for a given temperature of the annealing bath will appear saliently important. The reasons for this preference are obvious. We have in hand the highest of the inferior states of hardness permanently unaffected by the given circumstances of exposure; the maximum of *permanent* hardness, in other words. We are justified in ascribing to it greater uniformity of temper and greater definiteness of internal structure than is possessed by steel tempered in any other way whatsoever. Thus it will be possible, independently of the degree of carburization of steel, or of its chemical composition in general, independently, moreover, of the geometrical figure of a given sample, to investigate the magnetic variation due to the change of a single variable hardness alone. With this as a point of departure, the inquiry leads to the effect of form or dimensions, and ultimately to that of carburization.

ADDENDUM: ON A SIMPLE METHOD FOR THE GALVANIC CALIBRATION OF A WIRE.

The methods in vogue for the calibration of an electrical measuring wire, one, for instance, to be used in the Wheatstone-Kirchhoff bridge, are without doubt inconvenient in so far as they presuppose a set of resistance coils of known simple ratios. In other words, they call for the preliminary work of comparing with great care the said auxiliary coils. The accuracy of the result immediately sought is thus dependent on the accuracy of the earlier measurement, and the anticipative caliber errors of the wire are obscured by the errors possible in the accepted ratios of the coils themselves—particularly so where, as is generally the case, the discrepancies primarily in question are small. In view of the importance of the very accurate and convenient method of determining resistances by means of the sliding-contact bridge, the endeavor to overcome the obstacles mentioned as completely as possible is therefore at once justifiable. A method moreover which can accomplish this will be all the more acceptable in proportion as the auxiliary devices to be adopted are simple and readily available. We believe the following plan partakes of these advantages.

The method now to be described, and which we have profitably employed in determining the sectional errors of an electrical measuring wire, is a complete analogon of the procedure usually employed for the calibration of thermometers. The immediate principles and the point of departure are the same as those utilized in the well-known Matthiessen-Hockin method of resistance measurement. In the annexed figure, in which the ordinary bridge adjustment is diagrammatically given, let ANB and AMB be the two branches terminating at A and B , where

$A M B$ is the wire to be calibrated, $A N B$ a series of resistances, whose sum in any given case remains constant.

Now, if M_1 and N_1 , M_2 and N_2 are, respectively, pairs of points of like

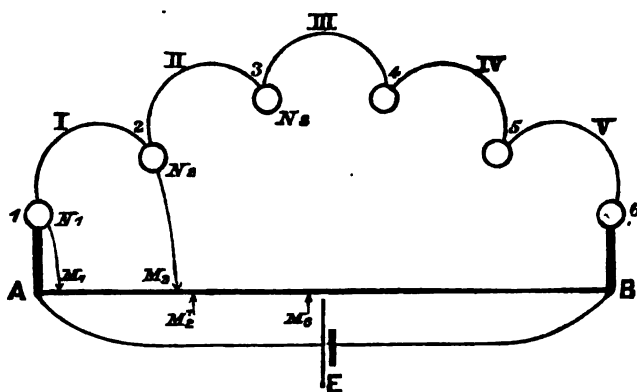


FIG. 12.—Disposition of apparatus for calibration.

potential, and if the resistance of $N_1 N_2$ be Y , and the length of the part $M_1 M_2$ be x , then

$$Y = C x,$$

where C is a constant (sensitiveness) dependent only on the sum of the resistances $A N B$. Indeed, if W be this sum, and L the total length of wire $A M B$, then

$$W = C L.$$

Furthermore, let the interval of calibration a be so chosen that $\frac{L}{a} = n$, where n is an integer.

Suppose, now, that n approximately equal resistances are either specially constructed or at the observer's disposal. In our case a number of tenths of Siemens mercury units, which had been made for the purpose of serving as normals for resistance comparisons, were available. But in general it is wholly sufficient to select a german silver wire of appropriate length and thickness, to cut it into n approximately equal parts, and then to solder the ends of each of these to terminals of thick copper, the free ends of which, in their turn, are to be amalgamated so that mercury contacts may be used at $N_1, N_2, \dots, N_n$ throughout. Further knowledge of the resistance ratio of these auxiliary wires is quite unnecessary.

These n approximately equal resistances $I, II, III, \dots$ are joined in series by mercury cups, as shown in the diagram. To have a concrete case, let $n=5$, for which assumption the figure applies. The extreme points A and B of the measuring wire are connected by pieces of thick copper with the extreme mercury cups. The calibration is then effected as follows:

One of the prolonged terminals of a sensitive galvanoscope is con-

nected consecutively with the points N_1, N_2 ; and by means of the other terminal the corresponding positions of the sliding contact on the wire $A M B$, viz, M_1, M_2 , respectively, determined.

Then I and II are exchanged, so that the resistance wire I now occupies the former position of II , and *vice versa*; and while one of the terminals of the galvanoscope is connected consecutively with the mercury cups N_2 and N_3 , the other enables us to determine the corresponding positions of the sliding contact on the wire $A M B$, viz, M_2' and M_3 , respectively.

After this, I and III are exchanged. The contacts of one galvanoscope terminal at N_3 and N_4 fix the positions of the sliding contact at M_3' and M_4 , respectively. And so on until I has passed consecutively from its original first position to the final portion among the whole series of resistances $A N B$. In this way we obtain on the wire $A M B$ the nearly consecutive parts $M_1 M_2, M_2' M_3, M_3' M_4 \dots$ of like resistance.

Herewith it is obvious that this method of galvanic calibration is strikingly analogous to the method adopted in thermometer calibration. In the latter case a mercury thread of a given constant convenient volume and the approximate length $a = \frac{100}{n}$ is moved from place to place in the tube, and its length for each of these positions determined in terms of the thermometer scale—lengths which under assumption of a constancy of caliber would be proportional to the volume of the thread, and hence identical. In the former electrical measurement, a wire of constant resistance is moved from place to place, and its value, as it were, determined in terms of lengths of the measuring wire, which again under conditions of constant sections would be proportional to the said moving resistance, and therefore identical. In both cases, finally, the sectional error of the tube or wire is shown by the discrepancies or differences in the observed lengths of mercury thread or wire-part, respectively. In thermometry, the two fixed points, with reference to which the calibration is completed, are the freezing and the boiling points of water. On the bridge the corresponding points coincide with the extremities A and B of the wire.

Let $a_1, a_2, a_3, \dots$ be the equivalent wire parts of $A M B$, determined by direct observation. Then will the mean length of these, which under assumption of a mean section of the calibrated wire corresponds to the calibration resistance, be

$$\frac{a_1 + a_2 + a_3 + \dots + a_n}{n}$$

But as a_1, a_2, a_3 differ but slightly from the calibration interval $a = \frac{L}{n}$, it is practically convenient not to introduce into the calculation the

whole lengths a_1 . . . a_n , but merely their (positive or negative) differences from a . Therefore let

$$a_1 = a + \delta_1; a_2 = a + \delta_2 \quad . . . \quad a_n = a + \delta_n$$

and similarly

$$\frac{a_1 + a_2 + a_3 + \quad . . . \quad a_n}{n} = a + \alpha.$$

Then, more simply, there follows

$$\alpha = \frac{\delta_1 + \delta_2 + \delta_3 + \quad . . . \quad \delta_n}{n}$$

and therefore for the table of calibration of the wire,

from 0 to a	$\alpha - \delta_1$
from a to $2a$	$\alpha - \delta_2$
from $2a$ to $3a$	$\alpha - \delta_3$, etc.

Therefore by summation:

$$\text{At } a, \text{ correction} = \alpha - \delta_1$$

$$\text{At } 2a, \text{ correction} = 2\alpha - \delta_1 - \delta_2$$

$$\text{At } 3a, \text{ correction} = 3\alpha - \delta_1 - \delta_2 - \delta_3, \text{ etc.}$$

As the main feature of the present method, we desire again to advert to the simple means by which the calibration is effected. The only error to be guarded against is the possibility of variation of temperature during the course of the consecutive adjustments of the calibration resistance. But the work can be accomplished rapidly—all the more as the approximate positions of M are readily predeterminable with considerable accuracy. If a fairly sensitive galvanoscope be employed the errors of adjustment are of the same order as the errors of observation. In case of our special bridge $2\frac{1}{2}$ meters long, very ordinary means enabled us to secure an accuracy of adjustment within 0.1 millimeter.

By means of the principle here enunciated any of the other methods of thermometer-calibration would be equally applicable. The convenient one given, however, is sufficient for all practical purposes.

CHAPTER III.

THE NATURE OF THE PHENOMENON OF TEMPER AS OBSERVED IN STEEL DISCUSSED FROM AN ELECTRICAL STANDPOINT—PARTICULARLY IN REFERENCE TO THE ANALOGOUS BEHAVIOR OF MALLEABLE CAST-IRON AND OF ALLOYS OF SILVER.

INTRODUCTION.

General inferences deducible from the cast-irons.—If we abstract from grossly impure material, details and ulterior complications, the different kinds of cast-iron may be conveniently classed with reference to two well-known types—the gray cast-iron and the white cast-iron—which are thoroughly distinct and well marked, as regards both their chemical and their mechanical properties. Reasons for this classification, it is believed, are not far to seek, and they are such as depend on the manner in which the carbon contained is combined with the iron. White cast-iron is known to contain carbon in the chemically combined state only. In gray cast-iron, however, the uncombined or mechanically admixed forms of carbon are present in much the greater proportion. Furthermore, it is known that a given specimen of molten iron may be changed into either the gray or the white type, respectively, according as the cooling, after casting, is permitted to take place very gradually or very rapidly.³⁷ In this respect an experiment of Karsten's³⁸ is peculiarly instructive. Karsten poured molten iron into a thick iron mold. The outer layers of the cold mass, which in this way had cooled at a comparatively rapid rate, were found to contain combined carbon only. In the inner and axial layers, however, where cooling took place gradually, only about one-sixth of the total carbon occurred in the combined form.³⁹ Suppose we compare the process of fast and slow cooling in the case of cast iron, with sudden chilling and very gradual cooling in case of steel, respectively; suppose, furthermore, we contrast the very high degree of hardness possessed both by white cast iron and chilled steel with the readiness with which gray cast-iron and slowly

³⁷ The remarks here made present the facts under consideration only in a brief and introductory way. For full and exhaustive discussions the reader is referred to Percy-Wedding, *Eisenhüttenkunde*, Bd. II of the German Percy, pp. 130-186, Braunschweig, 1864. Cf. particularly critical remarks, pp. 165-167.

³⁸ Karsten: *Eisenhüttenkunde*, Bd. I, 3 Aufl., 1841, p. 581 ff.

³⁹ The results of Karsten's analysis are these:

Before melting (iron homogeneous): C combined, 0.8 per cent.; C uncombined, 3.2 per cent.

After melting (outer layers): C combined, 5.1 per cent.; C uncombined, 0.0 per cent. Inner layers: C combined, 0.6 per cent.; C uncombined, 3.2 per cent.

cooled or thoroughly annealed steel yield even to an ordinary file; then the inference is apparently unavoidable that the hardness which may be imparted to steel by a process of tempering is to be referred to the transfer of carbon from the uncombined to the combined state.⁴⁰

Data corroborating this analogy.—If, however, what may be called the chemical method of accounting for the hardness in steel were alone dependent on analogies of the kind just sketched, we would not be inclined to accept it immediately and with full confidence. In glass-hard steel we encounter strains of a peculiar character, and of enormous intensity. It is upon such observations that a purely physical explanation of the hardness in question might be based—an explanation much better adapted for the prediction of certain physical phenomena to be mentioned below than the chemical view under consideration. At the very outset we come upon difficulties. Suppose, for instance, we attempt to draw further inferences from Karsten's experiment. We find that the glass-hard external layers of his cylinder, consisting wholly of white cast iron, possess the specific gravity 7.55, whereas the specific gravity of the gray nucleus was only 7.18. The effect of sudden chilling in case of steel,⁴¹ however, is a very marked diminution of density of the rod, as a whole. Even if we pursue our inference further, and endeavor to compare the external and internal layers of a glass-hard steel rod with the corresponding parts of Karsten's chilled iron cylinder, respectively, we fail to arrive at satisfactory results; for the density of the external layer of a steel bar (about 10) is incommensurately large when compared with the above datum for white cast-iron. The chemical explanation, however, at once becomes of incontestible importance when it is found that in addition to the given analogies we have in hand a number of data which go to prove that carbon exists differently, as regards its mode of occurrence, in hard and in soft steel. The data are derived from the chemical behavior of soft and hard steel toward acids. In this place the extensive experiments of Caron⁴² need alone be mentioned. The results of this observer with steel in the commercial, the hammered, and the glass-hard states, respectively, furnish striking evidence of the fact that the mode of occurrence of carbon in

⁴⁰ Cf. Karsten: Karsten u. v. Dechen's Archiv., XXV, p. 223, 1853. Cf., also, p. 103 of the present paper.

⁴¹ Karsten: op. cit., Bd. I, p. 193-4, experiments of Hausmann and Karsten. Cf. also *ibid.*, p. 184, ff. For a table for Swedish Bessemer steel, see "Steel, its history, etc.," J. S. Jeans, Sec. Br. Iron and Steel Inst., London, Spon, 1880; Cf. *ibid.*, p. 612-615. On the mean specific gravity of iron-carburets, cf. Karsten, op. cit., p. 183.

⁴² Caron: Comptes rend., LVI, p. 43, 1863. The residues in the cases referred to, viz., 1.62 per cent., 1.24 per cent., 0.24 per cent., were found to contain 0.83 per cent., 0.56 per cent., 0.00 per cent. of carbon, respectively. The following remark of Caron's moreover, is of especial importance here: "Ainsi de l'acier trempé ayant été recuit pendant un temps variant entre quelques heures et plusieurs jours a donné après dissolution des quantités de carbon libre qui ont augmenté en même temps que la durée et l'intensité des chauffes." pp. 45-46.

soft steel is thoroughly different from the chemical condition of this element in hard steel. In so far, then, as it is necessary to associate with this difference of chemical state of the carbon in steel some corresponding difference in the mechanical properties of this material, the validity of the chemical explanation of tempering may be said to have received its first important vindication.

Results at variance with chemical hypotheses.—Of late many facts have been adduced by various observers and in different ways against the hypothesis that the union of carbon and iron is ever of a thoroughly chemical character. Singularly clear in this respect are the views of Matthiessen,⁴³ who supposes that iron-carburets are to be regarded either as solidified solutions of carbon in iron, or as solutions containing carbon mechanically admixed. To these new opinions Matthiessen is led by a study of the electrical conductivity of these materials. With this general hypothesis the results of the calorimetric researches of Troost and Hautefeuille⁴⁴ are in strict accordance. These observers find that not only carbon but silicon show such thermo-chemical relations toward iron as call for a classification of iron-carburets with the category of solutions. Forquignon,⁴⁵ finally, who has lately been occupied with similar researches, gives to this view his unqualified assent.

Ultior consequences of the chemical theory in case of steel.—In connection with our researches on the hardness of steel a careful consideration of the subject in hand appeared necessary. Our attention was not, however, attracted to the questions just developed, viz., whether a chemical or mechanical explanation for the mode of occurrence of carbon in steel is more in coincidence with facts. The subject-matter of importance to us is sketched in all its essential points in the earlier sections. It is our endeavor to investigate whether a given change in the state of hardness of a steel rod is to be ascribed to a corresponding change in the mode of occurrence of the carbon in this material, or whether the presence of carbon imparts to iron certain distinct and unique properties ("steel") in such a way that the whole series of the phenomena observed in tempered steel are to be regarded as purely mechanical in their character. It may be observed that the first manner of explanation does not necessarily conflict with the second. Both chemical and mechanical phenomena may coexist. But it is best in this place to hold the two hypotheses strictly apart. This is readily possible, because the different states of hardness obtainable from a glass-hard steel rod by annealing are all reached, practically, when the temperature of the annealing bath is still below 350°, a temperature insufficiently high for the conversion of uncombined into combined carbon.

⁴³ Matthiessen: Rep. Br. Assoc. Adv. Sc., 1866, p. 15.

⁴⁴ Troost and Hautefeuille: Ann. de ch. et de phys. (5), IX, 1876, p. 70.

⁴⁵ Forquignon: Ann. de ch. et de phys. (5), XXIII, 1891, pp. 531-536.

Suppose now that we abstract from physical considerations altogether for the time being, and endeavor to obtain from the older and more thoroughly investigated chemical hypothesis an explanation for the details of the phenomena of annealing discussed in an earlier chapter.⁴⁶ If sudden chilling is accompanied by chemical combination of the carbon in steel, then must the operation of annealing, which reverses the effects of the former, enable us to reconvert combined carbon into its original uncombined state.⁴⁷ But we have shown that for each temperature of exposure during the annealing of a glass-hard rod there exists a distinct degree of hardness, *ceteris paribus*, characteristic of the temperature in question alone. It follows, therefore, that to each temperature of the annealing bath there must correspond a certain fixed ratio of combined to uncombined carbon, the time of exposure being indefinite. From the known behavior of steel in different states of temper, moreover, combined carbon, must be looked upon as electrically active, uncombined carbon as electrically neutral.* Thus we have it in our power, with the aid of the simple process of sudden chilling combined with subsequent annealing, in so far as in this way, within certain limits, any given amount of an electrically active ingredient may be converted into an electrically passive form, to reach the same results which, in the case of alloys, for instance, are obtainable only by melting the two component metals together in a ratio which may be called for. We said "within certain limits"; the superior limit here meant, is the total amount of carbon present in the given type of (normal) steel; the inferior limit, the small amount of combined carbon which even after most prolonged and gradual cooling cannot be made to appear in the uncombined state. With this chemical interpretation, finally, the remarkable linear relation between the thermo-electric constant and the specific resistance of steel passing continuously from the glass-hard to the soft state would at once appear to possess broader significance than that of being a special peculiarity of steel.

These are the reflections which induced us to undertake the present investigation. We were in hopes, moreover, that the results would prove of such a character as to enable us to derive inferences from them on the chemical nature of steel. At all events, the subject, considered from the standpoint of its own merits, is not undeserving of detailed attention. The number of data in hand on the relation in question is almost insignificant.

⁴⁶Strouhal u. Barus: Wied. Ann., XI, p. 962, 963, 1880. Chapter II, pp. 43 et seq.

⁴⁷Caron: l. c., pp. 45, 46. Unfortunately we have not been able to find any data relative to the effect of ordinary annealing (exposures below 400°) on the mode of occurrence of carbon in steel.

EXPERIMENTS WITH ALLOYS.

Earlier results inadequate.—The literature on the electrical conductivity of alloys is very voluminous, but the exhaustive researches of Matthiessen⁴⁸ contain all the essential data. At least, little has been developed that has a bearing on the present paper since the date of Matthiessen's main research.⁴⁹ From the tables and graphical constructions there given, the conductivity of a large number of alloys can be at once deduced when the proportion in which the ingredients of the alloy are mixed is known. Similar remarks by no means, however, apply to our knowledge of the thermo-electric properties of alloys. Qualitative results are not lacking. Available quantitative data are, however, very rare.⁵⁰ Pairs of values of both the electrical conductivity and the thermo-electric power of alloys are only to be found in isolated examples, if at all. At least we were not able to obtain other data than a few measurements incidentally made by Sundell.⁵¹

Matthiessen's numerous results made a special determination of data on the relation between percentage composition and either of the electrical constants superfluous. Such measurements presuppose chemical analysis, which could not have been made without unduly sacrificing the greater part of our wires and material. By weighing out the ingredients, and careful fusion, we were able to obtain from Matthiessen's tables a satisfactory corroboration of our results.

Material, fusion, preparation, etc.—The general plan adopted in our researches with alloys was such as would correspond to a progressive increase in the state of hardness of steel from the soft or thoroughly annealed to the glass-hard condition, premising the views discussed in the last section. We commenced with pure silver, to which more and more of a second metal was successively added, until finally mechanical difficulties were encountered such as prevented a drawing of the alloy to wire. In case of silver-gold alloys, a complete series, commencing with silver and ending with gold, were obtainable. The alloys examined are those of silver with gold, platinum, copper, and zinc. Silver and gold were obtained pure from the mint at Frankfort; platinum, from the shops of Heraeus in Hanau. The copper was deposited electrolytically from a copper-sulphate solution. In making the alloys we proceeded thus: A weighed amount of silver having been well fused on a bone-ash cupel by the aid of a blast-lamp, the proper quantity of the second metal was added to it. Solution is usually immediate. Having mixed

⁴⁸ Matthiessen: Pogg. Ann., CX, pp. 190-221, 1860.

⁴⁹ Matthiessen and Holzmänn: Pogg. Ann., CX, pp. 222-234, 1860; Rep. Br. Assoc. Adv. Sc., 1863, p. 37.

⁵⁰ We may, perhaps, mention Joule: Phil. Trans., 1859, I, p. 96 (Bi, Sb); Sundell: Pogg. Ann., CXLIX, 1873 (Bi, Sb, Sn).

⁵¹ Sundell: *Ibid.*, pp. 154-170.

the two component metals as thoroughly as possible by chasing the globule over the surface of the cupel, the flame was withdrawn and a glass bell-jar filled with hydrogen (the gas being continually resupplied through an aperture in the neck of the jar), quickly placed over it. Oxydation, as well as absorption of oxygen by the melted globule, was thus avoided, the button cooling in an atmosphere of hydrogen. Only in the case of silver-copper alloys is this simple process to be regarded insufficient for the attainment of very accurate results.⁵² But the discrepancies thus introduced into our work, and which are due to absorption of oxygen by copper, are quite insignificant. Of this fact a comparison of Matthiessen and Holzmänn's data with our own has fully convinced us. On the other hand, the variation of thermo-electric power and conductivity of alloys of silver and copper takes place within limits so nearly coincident that the general character of the diagram which we will endeavor to construct below is in nowise distorted.

The buttons⁵³ were hammered and drawn down to wires of appropriate diameter. These were then annealed at high red heat in a current of hydrogen by the aid of a dynamo-electric machine. We were able to regulate the intensity of current, and with it the glow, by introducing into the circuit a solution of copper-sulphate, in which the copper electrodes were kept at suitable distances apart. Accidental fusion of the hot wires was thus not to be apprehended. After this annealing they appeared soft and flexible. Only the middle parts of the wires, over the whole length of which the glow had been uniform, and which, for other reasons, were apt to be homogeneous, were reserved for the measurements.

Method of thermo-electric measurement.—Results.—The methods of measurement of thermo-electric power and specific resistance are identical with those employed in our earlier researches.⁵⁴ The former is throughout referred to pure silver as a datum, *i. e.*, denotes the power of a thermo-element, one part of which is always silver; the other, however, the given alloy. Junctions were carefully soldered. The composition of all alloys is given in volume per cents, the data expressing the volume of the metal alloyed to silver in 100 volumes of alloy. It has been stated that these numbers are only approximate, since during fusion the two metals will hardly have been volatilized in like ratios.

With these remarks the following tables (35–39) will be readily intelligible. The thermo-electric constants a and b are calculated on the basis of Avenarius'⁵⁵ formula, $e = a(T - t) + b(T^2 - t^2)$, from six corre-

⁵² Cf. Matthiessen u. Holzmänn: *l. c.*, pp. 222–224.

⁵³ It would have been desirable to operate with larger quantities of metal, but these were not at our disposal.

⁵⁴ See Chapter II, p. 31 *et seq.*

⁵⁵ Avenarius: *Pogg. Ann.*, CXLIX, p. 374, 1873. e is the electro-motive force for the temperatures T and t of the junctions of the given thermo-element whose constants are a and b .

sponding values of c , T , t , for each alloy, by the method of least squares. The measurements were originally made in Weber-Siemens' units, and then reduced to current values by the relation $\text{ohm}=1.06$ Siemens.

TABLE 35.—*Thermo-electric power of alloys.*

Alloy.	Vol. P. ct.	t	T	ϵ observed.	ϵ calculated.	Diff.	a	b
Silver-platinum.....	2	C.	C.	microvolt.	microvolt.			
		18.5	85.6	-308.6	-308.8	0.2	-3.95	-0.0051
		18.6	75.7	-261.3	-261.1	-0.2		
		18.7	64.1	-206.7	-206.7	0.0		
		18.7	53.6	-159.1	-159.1	0.0		
		18.8	43.1	-111.7	-111.9	0.2		
Do.....	5	18.8	36.3	-82.4	-82.3	-0.1	-5.72	-0.0090
		15.8	78.6	-413.0	-412.5	-0.5		
		15.9	69.3	-346.3	-346.4	0.1		
		15.9	60.9	-288.2	-288.5	0.3		
		16.0	52.3	-230.1	-230.1	0.0		
		16.1	45.8	-186.4	-186.5	0.1		
Do.....	10	16.1	37.5	-182.9	-132.7	-0.2	-6.77	-0.0134
		17.1	90.6	-604.4	-603.4	-1.0		
		17.1	79.1	-498.8	-499.6	1.3		
		17.1	68.3	-405.2	-405.0	-0.2		
		17.1	55.4	-296.8	-296.4	-0.4		
		17.1	45.2	-213.8	-213.7	-0.1		
Do.....	16	17.2	35.2	-134.4	-134.6	0.2	-7.90	-0.0158
		18.1	90.2	-710.6	-709.4	-1.2		
		18.1	74.0	-539.7	-539.5	-0.2		
		18.2	62.9	-425.6	-427.1	1.5		
		18.2	52.4	-324.9	-324.9	0.0		
		18.3	43.4	-239.4	-239.5	0.1		
		18.3	36.2	-174.0	-173.6	-0.4		

TABLE 36.—*Thermo-electric power of alloys.*

Alloy.	Vol. P. ct.	t	T	ϵ observed.	ϵ calculated.	Diff.	a	b
Silver-gold	5	C.	C.	microvolt.	microvolt.			
		15.5	85.1	-132.9	-132.9	0.0	-1.77	-0.0014
		15.5	75.5	-114.1	-113.7	-0.4		
		15.4	68.3	-99.1	-99.8	0.7		
		15.4	62.0	-87.8	-87.5	-0.3		
		15.4	50.6	-65.5	-65.5	0.0		
Do.....	15	15.4	40.0	-45.4	-45.4	0.0	-2.38	-0.0048
		15.4	89.5	-209.2	-209.5	0.3		
		15.5	80.0	-181.5	-181.6	0.1		
		15.5	71.5	-154.1	-154.0	-0.1		
		15.5	63.2	-129.7	-129.3	-0.4		
		15.6	52.8	-99.3	-99.3	0.0		
Do.....	25	15.6	44.1	-74.8	-75.0	0.2	-2.54	-0.0048
		15.7	90.2	-227.0	-227.0	0.0		
		15.7	82.6	-201.1	-201.3	0.2		
		15.8	66.3	-148.8	-148.0	-0.8		
		15.8	54.3	-110.8	-110.7	-0.1		
		15.8	44.9	-82.5	-82.3	-0.2		
Do.....	35	15.8	35.9	-55.9	-56.1	0.2	-2.61	-0.0039
		12.9	88.3	-223.6	-223.7	0.1		
		12.9	79.7	-195.8	-195.6	-0.2		
		12.8	72.3	-172.3	-172.1	-0.2		
		12.8	63.4	-144.2	-144.2	0.0		
		12.8	51.9	-109.2	-109.2	0.0		
		12.8	42.4	-80.9	-80.9	0.0		

TABLE 37.—*Thermo-electric power of alloys.*

Alloy.	Vol. P. ct.	<i>t</i>	<i>T</i>	<i>e</i> observed.	<i>e</i> calculated.	Diff.	<i>a</i>	<i>b</i>
		C.	C.	microvolt.	microvolt.			
Silver-gold.....	50	15.0	87.1	-202.3	-202.6	0.3	-2.39	-0.0041
		15.0	78.2	-175.4	-175.2	-0.2		
		14.7	65.6	-128.7	-128.5	-0.2		
		14.7	55.3	-108.9	-108.8	-0.1		
		14.7	44.4	-78.2	-78.3	0.1		
		14.6	38.2	-56.1	-56.1	0.0		
Do.....	75	14.1	86.1	-151.5	-154.4	+2.9	-1.71	-0.0048
		14.1	77.5	-135.1	-133.5	-1.6		
		14.1	68.0	-111.9	-111.4	-0.5		
		14.1	53.8	-79.3	-78.5	-0.8		
		14.1	42.1	-55.8	-54.7	-1.1		
		14.0	39.5	-30.7	-31.5	0.8		
Do.....	90	17.3	91.0	-116.0	-117.7	1.7	-1.41	-0.0017
		17.3	80.2	-100.8	-99.2	-1.6		
		17.3	68.1	-79.3	-79.3	0.0		
		17.3	57.0	-61.2	-61.0	-0.2		
		17.4	45.7	-43.8	-43.1	-0.7		
		17.4	34.6	-23.6	-25.8	2.2		
Gold.....	100	15.2	89.1	19.3	19.3	0.0	+0.275	-0.00012
		15.4	80.7	17.0	17.2	-0.2		
		15.5	70.9	14.8	14.7	0.1		
		15.6	60.5	12.2	12.0	0.2		
		15.6	51.4	9.6	9.5	0.1		
		15.7	40.3	6.5	6.6	-0.1		

 TABLE 38.—*Thermo-electric power of alloys.*

Alloy.	Vol. P. ct.	<i>t</i>	<i>T</i>	<i>e</i> observed.	<i>e</i> calculated.	Diff.	<i>a</i>	<i>b</i>
		C.	C.	microvolt.	microvolt.			
Silver-copper.....	2	14.6	83.7	0.3	-0.6	0.9	-0.023	+0.0001
		14.6	77.7	-1.2	-0.6	-0.6		
		14.6	69.2	-0.7	-0.6	-0.1		
		14.7	57.7	-1.2	-0.6	-0.6		
		14.7	48.0	-0.4	-0.5	0.1		
		14.7	39.8	-0.2	-0.4	0.2		
Do.....	5, 6	13.7	89.5	1.6	1.0	0.6	+0.021	-0.0001
		13.7	80.4	1.2	0.9	0.3		
		13.8	72.8	0.6	0.9	-0.3		
		13.9	62.8	-0.2	0.8	-1.0		
		13.9	52.2	0.5	0.6	-0.1		
		13.9	39.2	0.8	0.4	0.4		
Do.....	15	14.3	84.8	4.0	3.6	0.4	+0.041	+0.0001
		14.3	75.5	2.6	3.0	-0.4		
		14.3	65.3	2.5	2.4	0.1		
		14.4	56.5	2.0	2.0	0.0		
		14.4	46.8	1.4	1.5	-0.1		
		14.4	35.5	1.0	0.9	0.1		
Do.....	50	14.3	83.3	11.6	11.8	-0.2	+0.045	+0.0013
		14.3	72.9	9.0	9.1	-0.1		
		14.4	63.4	7.1	7.1	0.0		
		14.4	53.8	5.5	5.2	0.3		
		14.5	43.9	3.7	3.5	0.2		
		14.5	33.5	1.9	2.0	-0.1		
Do.....	75	16.2	86.9	8.7	9.2	-0.5	+0.020	+0.0011
		16.3	74.0	6.8	6.7	0.1		
		16.3	64.8	5.2	5.2	0.0		
		16.3	52.4	4.1	3.4	0.7		
		16.3	41.7	2.0	2.1	-0.1		
		16.3	33.0	1.0	1.2	-0.2		

(675)

TABLE 39.—*Thermo-electric power of alloys.*

Alloy.	Vol. P. ct.	t	T	e observed.	e calculated.	Diff.	α	b
		C.	C.	microvolt.	microvolt.			
Silver-zinc, with larger amount of zinc.	-----	15.5	87.0	- 8.8	- 8.6	-0.2	-0.024	-0.0009
		15.5	80.8	- 8.0	- 7.4	-0.6		
		15.5	71.5	- 4.9	- 6.0	+1.1		
		15.5	60.5	- 4.8	- 4.8	0.0		
		15.8	49.1	- 3.2	- 2.8	-0.4		
		15.8	25.3	- 1.3	- 1.4	+0.1		
Silver-zinc, with smaller amount of zinc.	-----	15.7	90.6	-12.8	-12.2	-0.6	-0.176	+0.0001
		15.7	81.0	-11.1	-10.7	-0.4		
		15.8	72.2	- 8.2	- 9.4	-1.2		
		15.8	58.3	- 7.1	- 7.1	0.0		
		15.8	48.0	- 5.7	- 5.4	-0.3		
		15.9	40.7	- 4.1	- 4.2	0.1		

Specific resistance.—The following table contains our data for the specific resistance of the same alloys to which the foregoing tables (35–39) refer. The first two columns need no explanation. Column third contains the resistance in ohms per meter of wire at the temperature in column fourth. Under 2ρ the diameter and under s , the specific resistance in micro-ohms at the temperature t is given. The constant α , finally, whose signification is apparent from $s_t = s(1 + \alpha t)$, enables us to calculate s , the specific resistance at zero centigrade, in micro-ohms.

It is to be remarked that all the measurements were originally made in Siemens' units (ohm=1.06 Siemens), and subsequently reduced. The temperature-coefficients used, α , are obtained from the results of Matthiessen, C. Vogt, and v. Bose,⁵⁶ by calculating with the aid of their formulæ, s , for 100° and 0°, and then finding the mean coefficient (α) between these limits. This is obviously permissible in our case.

TABLE 40.—*Electrical resistance of alloys.*

Alloy (soft).	Vol. P. ct.	W 1 m	t	2ρ	s_t $\frac{\text{cm}}{\text{cm}^2}^\circ$	α	s $\frac{\text{cm}}{\text{cm}^2}^\circ$
		obs.	C.	cm.	microhm		microhm
Commercial silver	100	0.2023	15.2	0.0319	1.619	0.00398	1.521
Electrolytic silver	100	0.1777	15.4	0.0337	1.580	0.00396	1.492
Do	100	0.1809	15.0	0.0335	1.586	0.00398	1.491
Silver-platinum	2	0.2431	11.3	0.0495	4.67	0.00130	4.60
Do	8	1.0802	15.2	0.0320	9.21	0.00672	9.11
Do	10	0.8054	11.0	0.0496	15.53	0.00043	15.46
Do	75	2.4027	15.2	0.0347	22.74	0.00038	22.63
Silver-gold	5	0.3887	15.5	0.0337	3.463	0.0025	3.329
Do	15	0.7483	15.6	0.0337	6.696	0.0012	6.561
Do	25	0.9886	15.7	0.0339	8.906	0.0008	8.790
Do	35	1.1350	15.1	0.0338	10.188	0.0007	10.079
Do	50	1.2098	15.4	0.0327	10.700	0.0007	10.585
Do	50	1.2190	15.2	0.0337	10.782	0.0007	10.667
Do	75	0.9177	16.2	0.0329	8.295	0.0009	8.174
Do	90	0.2772	11.2	0.0493	5.233	0.0016	5.188
Gold	100	0.1137	18.0	0.0485	2.193	0.00295	2.037
Silver-copper	2	0.2049	15.0	0.0338	1.844	0.0086	1.744
Do	5.6	0.1038	11.0	0.0496	1.999	0.0034	1.924
Do	15	0.2292	16.8	0.0344	2.131	0.0032	2.016
Do	50	0.2370	16.2	0.0358	2.383	0.0029	2.271
Do	75	0.2314	16.7	0.0352	2.255	0.0031	2.138
Silver-zinc	-----	0.1738	17.4	0.0500	3.403	(0.0020)	(3.28)
Do	-----	0.2114	15.6	0.0500	4.151	(0.0015)	(4.06)

⁵⁶ Matthiessen u. v. Bose: Pogg. Ann., CIII, p. 412, 1858.

The following table (41) contains results of Matthiessen and others; a and b here are Matthiessen's constants for his relation between electrical conductivity and temperature. By means of these λ and λ' , the electrical conductivity at 0° and 100° , respectively, were calculated. But, according to Matthiessen, $\lambda=100$ for hard silver; $\lambda=1.656$ for mercury, (0°). Hence

$$s_t = \frac{100}{\lambda_t} \frac{1.656}{1.06} \quad \log s_t = 2.19375 - \log \lambda_t.$$

From these values of s_t the constant α was then obtained, in the way already given, $s_t = s(1 + \alpha t)$.

TABLE 41.—Specific resistance of alloys of silver.

[Results of Matthiessen (and C. Vogt).]

Metal	Hard or soft.	Vol. Per ct.	λ at 0° Ag (h) =100	a	b	λ' at 100° Ag (h)=100	$s \frac{\text{cm}}{\text{cm}^2} 0^\circ$	$s \frac{\text{cm}}{\text{cm}^2} 100^\circ$	$\alpha \dots 100^\circ$
Silver	h	100	100	0.38287	0.0009848	71.561	microhm.	microhm.	0.003974
Do	s	100	106.74	0.41870	0.0010624	77.794	1.5623	2.1831	0.003978
Silver-platinum	h	2.51	31.640	0.033963	0.00003642	28.068	4.938	5.566	0.001272
Do	h	5.05	18.081	0.018949	0.00001183	16.754	8.064	9.325	0.000763
Do	h	12.65	6.696	0.002214	0.00000129	6.489	23.331	24.075	0.000319
Silver-gold	h	19.86	21.064	0.019185	0.00001152	19.581	7.205	7.858	0.000906
Do	h	52.08	15.030	0.010120	0.00000370	14.055	10.394	11.115	0.000694
Do	h	79.86	21.335	0.023212	0.00001694	19.188	7.322	8.144	0.001123
Do	s	19.86	21.746	0.019753	0.00001895	19.910	7.184	7.847	0.000928
Do	s	52.08	15.080	0.010864	0.00000748	14.068	10.360	11.105	0.000719
Do	s	79.86	21.584	0.024539	0.00002506	19.381	7.238	8.061	0.001137
Gold	h	100	77.964	0.28648	0.0006582	55.898	2.0088	2.7948	0.003947
Do	s	100	79.327	0.29149	0.0006697	56.875	1.9694	2.7468	0.003947
Silver-copper	h	1.53	79.708	0.32868	0.0006965	58.805	1.960	2.904	0.004816
Do	h	3.25	80.284	0.22101	0.0003503	61.696	1.946	2.533	0.003017
Do	h	46.67	74.940	0.21011	0.0003961	67.890	2.085	2.699	0.002946
Do	h	77.64	69.811	0.21194	0.0004240	52.857	2.238	2.956	0.003208
Do	h	95.17	82.300	0.26758	0.0006717	61.259	1.898	2.550	0.003442
Do	h	98.35	89.544	0.30886	0.0007155	65.813	1.745	2.374	0.003806
Copper	h	100	99.947	0.39681	0.0009004	70.270	1.5631	2.2232	0.004223
Do	s	100	102.213	0.39557	0.0009208	71.864	1.5297	2.1739	0.004211

Digest. Diagram.—For the sake of perspicuity, the final results are tabulated again as follows.

TABLE 42.—Corresponding values of the galvanic and thermo-electric constants.

Alloy.	Volume Per cent.	$s \frac{\text{cm}}{\text{cm}^2} 0^\circ$	α $\left(\frac{ds}{dT} \right)_{(T+t)=0}$
Silver-platinum	0	microhm.	0.00
	2	1.49	—3.95
	5	4.60	—5.72
	10	9.11	—6.77
	15	15.46	—7.90
Commercial-platinum	100	22.63	(0.38)
		*(8.67)	
Silver-copper	0	13.44	0.000
	2	1.49	—0.023
	5, 6	1.74	0.021
	15	1.92	0.041
	50	2.02	0.045
	75	2.27	0.020
	100	2.14	(—0.114)
		1.53	

* Applies for chemically pure metals. These values in parentheses are approximate, and are not immediately derived from observations.

TABLE 42.—Corresponding values of the thermo-electric and galvanic constants—Cont'd.

Alloy.	Volume. Per cent.	$\frac{s \text{ cm}^2}{\text{cm}^2}$	α $\left(\frac{de}{dT-1}\right)_{(T-1)=0}$
		microhm.	
Silver-gold	0	1.49	0.00
	5	3.38	-1.77
	15	6.56	-2.38
	25	8.79	-2.54
	35	10.08	-2.61
	50	10.63	-2.39
	75	8.17	-1.71
	90	5.19	-1.41
	100	2.04	0.27
Silver-zinc	0	1.49	0.000
	>	(3.28)	-0.624
	>	(4.06)	-0.176
	100	5.38	(-0.098)

The results contained in the last table (42) are given graphically in figure 13, specific resistance being represented as abscissa, thermo-electric

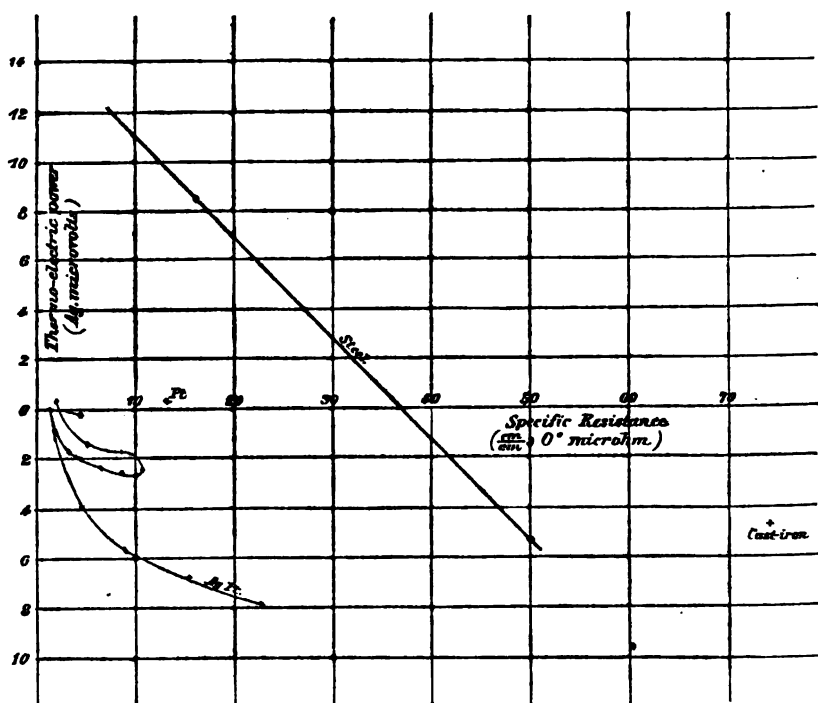


FIG. 13.—Specific resistance and thermo-electric constant: steel, silver-gold, silver-platinum, silver-zinc.

tric constant as ordinate. In order to facilitate comparison the linear relation which holds for steel (see chapter II, page 63) is also drawn,

and the interval of variation⁵⁷ of the constants in question indicated by two small circles near the ends of the line. All the constants are given in microhms and micro-volts, respectively, and the thermo-electric position is referred to silver.

Discussion.—A mere glance at the curves tells us that the relations under consideration are by no means of a simple character. Both properties, as exemplified by the thermo-electric constant and specific resistance, pass through maxima or minima, in such a way, however, that the said singular points do not coincide—*i. e.*, are not properties of one and the same wire as regards composition. Equally difficult is it to observe any perspicuous law for the direction of the line joining the extreme points (those corresponding to pure metals) of the curves. The very simple relations which obtain in case of steel would apparently lead to the anticipation of some result of this kind.

The given curves, however, apply only for fixed conditions of temperature; the galvanic constant s only for the temperature $t=0$; the thermo-electric constant α for the mean temperature $\frac{1}{2}(T+t)=0$. But the temperature-coefficient, both for thermo-electric power⁵⁸ as well as for specific resistance, varies in a marked degree as we pass from alloy to alloy. Hence it follows that for each temperature there exists a set of curves of the kind in question, characteristic of the said temperature. Change of temperature, therefore, involves a change in the curves both in figure and in position. It follows herefrom that a certain temperature must exist for which the figure of the curves is the simplest possible; our knowledge of the effects of temperature is, however, as yet insufficiently accurate to enable us to adduce further inferences. It is to be noticed that, at least as far as the above experimental matter is concerned, the magnitude of the given curves—*i. e.*, the range of variation of the involved electrical constants—is qualitatively in the order of the differences of the specific volumes of the metallic components of the respective alloys. The very large loop, obtained in the experiments with silver-platinum alloys, corresponds to the marked increase of hardness which these materials experience with increasing additions of platinum to silver. On the other hand, in the case of silver-gold and silver-copper alloys, a very great difference in the extent of the loop is apparent, unaccompanied by corresponding differences in the degrees of hardness⁵⁹ of the respective alloys. That the bulge in the different curves must be wholly to the right of the lines joining the extreme

⁵⁷ In later researches the superior limit was found to be even above 50.

⁵⁸ In reference to thermo-electric power we consider the quantity $2b$ in the equation $e = a\tau + b\tau\sigma$ as a kind of temperature coefficient, since the thermo-electromotive force e for a given difference τ , of temperature, increases linearly with $\frac{\sigma}{2}$, the mean temperature of the junctions.

⁵⁹ We shall find below that hardness may also exist in iron-carburets without a marked electrical equivalent.

points is known. Finally it may be called to mind that the direction of the initial tangent at the point "silver" $\left(\frac{da}{ds}\right)_{s=0.017}$ throughout the above results is negative.⁶⁰ The thermo-electric effect of the addition of small amounts of other metals to silver would therefore appear to be a progression in a thermo-electrically negative direction.⁶¹ The number of alloys here examined is too small to permit us to attach much significance to this fact. Nevertheless it follows that the thermo-electric relation of any given metal to another does not, so far as can now be seen, enable us to predict the effect produced when the first metal is alloyed to the second. Gold and platinum, for instance, are both positive as regards silver; the initial alloys silver-gold, silver-platinum, however, are negative as regards silver.

THE GENERAL PHENOMENON OF TEMPER REGARDED FROM THE CHEMICAL AND FROM THE MECHANICAL STANDPOINT.

Inferences from the behavior of alloys.—We now desire to consider the bearing of the above results on the electrical properties of steel. From the standpoint of the chemical theory of tempering, it is permissible to regard the linear locus, thermo-electric power varying with resistance, as the initial tangent of a loop of comparatively enormous magnitude. (See figure 13.) The increment of resistance with increasing hardness, or, in other words, with an increase of the ratio of combined to uncombined carbon, is to be considered analogous to the increase of resistance encountered on alloying small amounts of any metal to any given other metal. The linear relation can hardly be regarded striking, since in the case of steel the maximum amount of available carbon does not exceed one to two per cent. Finally, the magnitude of the variation or the extent of the loop might again have been anticipated, from the fact that here a metalloid is alloyed to a metal. The question, therefore, at once suggests itself, in how far these results are corroborated by the electrical behavior of cast-iron. In another paper we will show that the specific resistance of cast-iron, when in a condition corresponding to that of hard steel, i. e., when by means of sudden cooling as much carbon has been converted into the combined form as possible, may be increased to $100 \frac{\text{cm}}{\text{cm}^2} 00$ microhm. That is, the specific resistance of chilled cast-iron is nearly as

⁶⁰ The isolated negative value for the two per cent. copper alloy might be regarded suspiciously in consequence of the difficulties encountered in endeavoring to obtain these alloys free of oxygen. But its specific resistance shows no anomalous behavior.

⁶¹ Thermo-electrically negative in Seebeck's sense. Cf. Wiedemann, *Galvanismus*, 3 ed., p. 248, 1883.

large as that of mercury. Suppose, now, we compare the variation of specific resistance (superior limit $s = 50 \frac{\text{cm}}{\text{cm}^3} 0^\circ \text{microhm}$) in the case of steel, where the amount of combined carbon cannot exceed 1 to 2 per cent., with the corresponding variation of specific resistance (superior limit $100 \frac{\text{cm}}{\text{cm}^3} 0^\circ \text{microhm}$) in the case of cast-iron, where the combined carbon can be increased as high as 5 per cent.; then it apparently follows at once that the electrical behavior of cast-iron is such as we would be justified in predicting from the known relations in case of steel, if we accept the chemical hypothesis of tempering.⁶² Hence neither the simple relation of thermo-electric power and specific resistance discovered for steel, nor the phenomenal variation of these constants with the state of hardness of this material, are further to be looked upon as remarkable. We will return to this subject again, below.

It follows from what has been said, that our hope of being able to throw additional light on the nature of the phenomenon of temper in case of steel from a detailed study of the analogous electrical behavior of alloys was not realized. For although on the one hand the new data furnish no results antagonistic to the chemical theory, on the other they leave us without satisfactory or additional reasons for accepting the same. Under these circumstances it is necessary to contrast the theories which may be advanced for the explanation of temper with full regard to all known facts. This we will endeavor to do in the following, particularly so as the discussion will show where good work has been done done and where crucial data are still lacking.⁶³

Electrical resistance a volume function.—The discussion may be appropriately commenced with the examination of certain mechanical phenomena which accompany hardness in steel. It is known that the effect of tempering to glass-hardness is an increase both of the specific resistance and the specific volume of steel. This, however, is analogous to the effect of temperature in the case of metals generally. The question is therefore at once suggested, in how far a given increment of volume in the case of steel, whether produced by temperature or by tempering will be accompanied by the same increment of specific resistance. We

⁶² Cf., however, p. 186.

⁶³ In this place it will be well to refer to certain memoirs which have a definite bearing on the subject-matter in hand. In addition to Karsten, Hausmann (*Molecularbewegungen*, 1856, p. 48), Tunner (*Leob. Jahrbuch*, x, p. 480, 1861), Jullien (*Bullet. de la Soc. de l'industrie minérale*, I, p. 566; II, p. 202, 644), Hezner (*Berg- u. Hüttenm. Ztg.*, 1862, p. 140), Deville (*Dingler's Journal*, clxviii, p. 174), Caron (*ibid.*, p. 36) have developed theories on the causes of hardness in steel. For a discussion the reader is referred to Kerl's *Metallurgy*, 1870, Vol. III, pp. 25-7, translated by Crookes and Röhrig. It is not our object to enter into a critical examination and comparison of these, as we propose simply to consider the inferences which may be drawn from the electrical behavior of iron-carburets.

were fortunate in finding a sufficient number of data in the literature of steel to enable us to make a preliminary calculation or estimate.

Let v_2 and v_1 denote the specific volume of steel in the glass-hard and soft states respectively. Then the results of Fromme⁶⁴ with steel rods whose diameters (0.27 centimeter and less) are nearest those of our own (0.10 centimeter and less) may be thus expressed:⁶⁵

$$\frac{1013}{1000} > \frac{v_2}{v_1} > \frac{1012}{1000} \quad \dots \quad (1)$$

Suppose we put $v_2 = v(1 + 3\beta t)$, where $\beta = 12:10^6$, meaning thereby that the volume-increment $v_2 - v$ is due to an increase of temperature t . Then we find

$$360^\circ > t > 330^\circ \quad \dots \quad (2)$$

Since β will probably increase with temperature, this inequality might approximately be expressed $t = 300^\circ$.

Experiments on the resistance effect of high temperatures were originally made by Müller.⁶⁶ By the aid of his data for the resistance of iron at 21° , 285° , "oxide-tints appear" (300° to 350°), we deduce, if s' and s be the specific resistances of steel at 300° and 0° , respectively,

$$3.6 > \frac{s'}{s} > 2.5 \quad \dots \quad (3)$$

where the superior limit is possibly too small. The more recent results of Benoit,⁶⁷ however, furnish us more accurate values. Let $\frac{s'}{s}$ refer to an interval of temperature between $0^\circ - 330^\circ$ and $0^\circ - 360^\circ$. Then Benoit's special formulæ and constants for steel give us the relation:

$$3.7 > \frac{s'}{s} > 3.4 \quad \dots \quad (4)$$

If, finally, s' and s denote the specific resistance of good steel in the glass-hard and soft states, respectively, then our results have shown⁶⁸

$$3.0 > \frac{s'}{s} > 2.5 \quad \dots \quad (5)$$

If we compare the estimates expressed in the inequalities (3), (4), (5), it becomes at once apparent that the results of Fromme, together with those of Müller and Benoit, are more than sufficient for the explanation of the enormous increase of resistance which a steel rod tempered to glass-hardness, experiences. It follows that in the case of steel, a given increment of specific volume, whether produced by temperature

⁶⁴ Fromme: Wied. Ann., VIII, p. 354, 1879.

⁶⁵ These inequalities are not general in their signification. Their purpose is merely that of expressing the extent of the interval within which the cited data were observed to lie.

⁶⁶ Müller: Pogg. Ann., CIII, p. 176, 1858. It is hardly necessary to distinguish between iron and steel here.

⁶⁷ Benoit: Comptes rend., LXXVI, p. 342, 1873; cf. Carl's Rep., IX, pp. 55-9, 1873.

⁶⁸ The predominant influence of carbon on the ratio $\frac{s'}{s}$ will be referred to elsewhere.

or by tempering, is accompanied by increments of specific resistance of the same order. Of course, a result of this kind, since the rod remains homogeneous throughout in one case and is subjected to extremely complicated structural modification in the other, cannot be rigidly true. Nevertheless, the approximate data are of the greatest importance, because they demonstrate conclusively that the effects of the operation of tempering, even if regarded as of a purely mechanical character, must be attended by electrical phenomena of the same order as those which are actually observed.

(2) There is another question intimately connected with the one just discussed, viz, whether a given decrement of volume,⁶⁹ produced either by pressure alone or by temperature alone, is always attended by the same diminution of resistance for the same substance (metal); or whether it is necessary to postulate the existence of a purely thermal influence in the second case. Chwolson,⁷⁰ who has subjected wires of copper, brass, and lead to pressure, infers that the resistance and the specific volume of these substances vary in like ratio.

In Chwolson's experiments the effects due to pressure are so nearly commensurate with the errors possibly introduced by temperature that we are justified in approaching his results with some diffidence. Marked compression is not readily attainable by piezometric methods. With steel, however, the result, which more than verifies Chwolson's inference on the resistance-effect of volume-reduction, may be thus illustrated.

Let $s_t = s_0 (1 + \alpha t)$. Specific resistance (s_t) is here regarded as a temperature (t) function. Then, if t be supposed to decrease indefinitely, the equation $s_t = 0$ would be satisfied at about

$$t = -250^\circ \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

provided, of course, the given relation holds.⁷¹

On the other hand, let

$$s_2 = s_1 \left(1 + k \frac{v_2 - v_1}{v_1} \right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where the specific resistances s_2 and s_1 correspond, respectively, to the volumes v_2 and v_1 , and k is a constant. Specific resistance is here regarded as a volume-function.

²⁰In the case of mercury, for instance. The results for solids would be distorted by the loss of structural homogeneity of the compressed solid resulting from external pressure. Large increment of volume is probably only obtainable by tempering steel, and to this enlargement of mean specific volume the remarks already made apply.

⁷⁰Chwolson, *Carl's Rep.*, XIV, 26, 27, 1878.

¹¹ The temperature coefficient here accepted is the one found for soft steel in chapter I, p. 19, viz. $\alpha=0.004$.

(3) The results of Fromme⁷³ and Chwolson finally contain a remarkable analogy, to which attention has not yet been given. If the hardness of a glass-hard steel rod be supposed to decrease continuously, then the specific volume will be found to pass through a minimum, as Fromme has emphasized, at a state of hardness corresponding to the annealing tint, "gray" (annealed at 300°-500°). Chwolson experimented on a very large number of metals and alloys. He found that the electrical effect of "drawn" hardness as well as the hardness due to sudden chilling vanishes on exposure of the hard wire to high temperature, in such a way that after the first gentle ignition at low red heat the specific resistance of all metals passes through a minimum.⁷⁴ Unfortunately Fromme has not interpolated a temperature which would produce an effect between "gray annealed" and "soft." Nevertheless it is difficult to avoid the conclusion that in all these examples of minima we encounter phenomena essentially of the same kind. Chwolson remarks that in case of steel his results were singularly striking. It would appear, therefore, that the mechanical effect (electrically measured) of sudden cooling is the same for almost all metals; that the magnitude of this effect differs from metal to metal, and is enormously pronounced in steel. This is the first evidence adduced that the given operation, tempering, produces qualitatively like effects on metals generally, the difference being in degree only.⁷⁵

(4) In view of the increasing importance of density or of the values of specific volume in all these instances, the fact that in the above experiments with alloys the ranges of variation were found to be in the order of the differences of specific volume of the metals composing the alloy may again be called to mind. In case of steel the intimate relationship between specific resistance and thermo-electric power, described elsewhere, suggests that the cause of the increase of volume consequent upon sudden cooling is of a purely mechanical character, i. e., that it is not the direct result of the change of chemical condition of steel which tempering probably produces.

"*Drawn*" hardness.—Matthiessen⁷⁶ found that a hard-drawn wire of silver could be very perceptibly annealed (conductively decreased) by continued boiling in water. We obtained a good corroboration of this

⁷³Fromme, l. c.

⁷⁴Lead and German silver are exceptions.

⁷⁵It must be borne in mind that this remark refers to the electrical indication of the (mechanical) effect of tempering. It is well known that while sudden chilling hardens steel, it is said actually to soften some of the other metals. It is, however, exceedingly difficult to distinguish between the degrees of hardness of brass or copper suddenly chilled or slowly cooled from red heat, by ordinary mechanical means; and, moreover, sudden cooling may be accompanied by purely chemical effect in alloys and (not chemically pure) metals as it is in case of steel.

⁷⁶Matthiessen, und v., Bose: Pogg. Ann., CXV, p. 363, 366, 370, etc., 1862.

result with drawn German-silver wire,⁷⁷ in which, after an exposure to steam at 100° of only an hour, a change of resistance of about 0.25 per cent. was perceptible. It follows, therefore, that not only tempered but drawn wires may be annealed to a very marked degree at comparatively low temperature.

Inferences from the behavior of iron-carburets.—(1) In chapter I we saw that the temperature-coefficient of cast-iron is in good accordance with the coefficients of wrought iron and of steel in different states of temper, so that in this respect all the iron-carburets form a single connected series.

(2) This is by no means the case if we compare the relative galvanic and thermo-electric behavior of these products. From an inspection of figure 13 it is at once obvious that the position of cast-iron is isolated relatively to the linear locus which obtains for steel. This observation shows conclusively that in the case of steel the cause of the electrical variation in question must be essentially different from that which determines the position of cast-iron. Below it is shown to be necessary to explain the distinctive electrical qualities of cast-iron as effects of chemical composition. Hence we infer with some assurance that the electrical behavior of steel on passing from one state of temper to another, since the succession of values in no way suggests the electrical qualities of cast-iron, is conditioned by the cotemporaneous and purely mechanical changes which steel undergoes.

Phenomena of annealing chemically interpreted.—On endeavoring to use the chemical hypothesis of tempering to account for the phenomena of annealing,⁷⁸ we at once encounter serious difficulties. On the basis of this theory there must exist a fixed ratio of combined to uncombined carbon for each temperature of the annealing bath. Moreover, for a given temperature this ratio must be approached gradually (asymptotically) as time of exposure is prolonged indefinitely; for different temperatures it must decrease as temperature increases indefinitely, until finally a minimum value wholly independent of temperature is asymptotically reached.⁷⁹ The minimum of the ratio of combined to uncombined carbon need not, of course, be zero. The last phase of this species of decomposition is in many respects similar to the phenomena of dissociation. The resemblance can, however, only be apparent, since continuous dissociation has not been observed except in the case of gases. At least, in our knowledge, there are no chemical examples in

⁷⁷ The results are these: Before boiling: 12° 4, $r=6.8522$; 12° 5, $r=6.8523$; 12° 6, $r=6.8524$. During boiling: 99° 8, $r=7.0167$, $r=7.0182$, $r=7.0204$; resistance (r) measured successively. After boiling: 13° 5, $r=6.8691$; 13° 6, $r=6.8694$; 13° 7 $r=6.8696$.

⁷⁸ Strouhal und Barus: Wied. Ann., XI, p. 962, 1880.

⁷⁹ In these cases of annealing slow cooling of the annealed rod after exposure to the annealing temperature is always presupposed. It is thus that annealing at red heat is synonymous with softening ("Ansglühen"). This operation does not, however, convert all the carbon in steel to the uncombined form, in which case the said ratio would be zero.

which solids are found to dissociate in accordance with the laws to which gases, in virtue of their physical state, must conform; and for this reason the explanation of the phenomena of annealing given by the chemical theory is remote and forced, and to be discarded. We gain no more by adopting Matthiessen's hypothesis, which considers all iron-carburets as solidified, more or less thorough solutions of carbon in iron.

Annealing physically interpreted.—It is not difficult, however, to find for the phenomena of annealing a satisfactory explanation of a purely mechanical character. We proceed in a manner analogous to the way in which, in the case of soft rods of the same dimensions, what is known as coercive force¹⁰ in magnetism is sometimes defined. To this analogy we will recur again.

(1) It will be permissible in this place to introduce a definition of viscosity which is conveniently adapted to our present purposes. We will suppose the viscosity of steel to be measured by the maximum of strain of a given kind (in the present research the strain accompanying hardness) which a steel rod of given dimensions, after previous condition of supersaturation, of itself, permanently retains. The process of tempering to glass-hardness, therefore, is essentially one by which energy is stored up, whereas during the operation of annealing the stored energy is again more or less gradually expended; and the maximum energy permanently potentialized, under given circumstances of temperature (the same rod always presupposed), increases directly with the maximum intensity of permanent strain under the same circumstances. Practically, however, we possess no means for the absolute evaluation of either of these quantities. But in so far as both thermo-electric hardness and specific resistance (the rod being in the state of the maximum of permanent hardness as regards the given temperature) vary directly with strain and stored energy, we may accept either of the former quantities as furnishing a good general estimate of the magnitude of the latter. In the case of one and the same steel wire viscosity is an inverse function of temperature and of temperature only. In the case of wires which differ quantitatively though not qualitatively as regards carburization, and are otherwise identical, viscosity is a function both of temperature and carburization (carburization < 2 per cent.), decreasing with the former and increasing with the latter magnitude.

(2) The difference between the phenomena of annealing and the phenomena of viscosity, as ordinarily studied and observed, is succinctly this, that in the latter case stress or a single force is applied from without to produce the gradual and permanent deformation through infinite time; in the former, however, stress exists in the rod itself (strain of hardness), but can be made to disappear in the asymptotic way characteristic of these phenomena by decreasing the viscosity of the rod as a whole; i. e., increasing its temperature. In other words, in the ordinary

¹⁰ Cf., for instance, Monsson: Physik, 2 ed., Vol. III, p. 86.

case of viscosity-measurement the phenomenon is evoked by sudden application of stress (torsion, tension, flexure, volume-compression) at constant viscosity; in the present case by sudden decrement of viscosity at initially constant stress. For instance, given a glass-hard rod at ordinary temperatures. Let its temperature be raised to 100° . The stress which was just permanently maintained at the lower temperature is in excess at the higher, because of the diminished viscosity of the rod, as a whole; and this excess must therefore disappear gradually through infinite time, precisely as we have observed it. If, furthermore, the diminution of viscosity be sudden and very large (annealing at high temperatures 200° , 300° , &c.), stress will disappear at a correspondingly rapid rate; etc.

In this way we are able, as a first approximation, to refer the phenomena of annealing to the general category of phenomena of viscosity. But for the reason of the deformation accompanying the existence of internal stress, for the reason that the degree of heterogeneity of a hard rod varies to a greater or less extent with each variation of stress as well as temperature, it is difficult to form any clear conception of the viscosity of the rod, as a whole, except by the aid of such a definition as is given at the beginning of the present paragraph. We will waive a further development of these views here for the reason that the details of operation of tempering itself are in need of further experimental elucidation, in various directions. Here, however, an account of the occurrences which rob the theory just sketched of much of its clearness and perspicuity is in place.

(3) The most satisfactory conception which we can form of the nature of the strain of a glass-hard steel rod is that of abnormally condensed external layers surrounding, like an arch, an abnormally rare core. These two abnormal states of density mutually condition each other. It is the stress under which the internal layers exist which is the cause of the condensation of the relatively thin external shell, and the extreme limit of condensation of the latter, again, which prevents the internal layers from falling back to normal density. This view has much experimental evidence to support it,⁸¹ though it must be regarded as a mere *diagram* of the essential features of the vastly more complicated structure of the glass-hard rod. An increase of the temperature of a hard rod (annealing) is antagonistic to the existence of a strain of this character in two respects. In the first place it is obvious that the rare core will be in a condition of less intensity of strain at a high than at a low temperature, and this because of the volume-expansion due to temperature. For, instance, the temperature may readily be chosen so high that an identical hot rod would normally have the same low density that originally existed in the strained core of the cold glass-hard rod. Increase of temperature, on the other hand, diminishes the den-

⁸¹ Cf. Mousson: Physik, 2. ed., pp. 224, 225, Vol. I, 187. Fromme: l. c.

sity of the external layers. In proportion, therefore, as the temperature of the annealing bath is higher, the inner layers of the originally hard rod approach the normal density for the respective temperatures more and more nearly, and the surface condensation, because the conditions of its existence are being annulled, must therefore also disappear at a corresponding rate. When the temperature, t^0 , at which the stress in the inner layers is wholly gone has been reached, only as much of the surface condensation can have remained as is in conformity with the ordinary viscosity of steel at t^0 . The rod if cooled from t^0 will therefore in the cold state be of greater density than an otherwise identical and homogeneous rod—it being postulated, of course, that with the disappearance of strain the tempered rod itself approaches nearer and nearer the homogeneous state. If the annealing be carried to even higher temperatures than t^0 , the surface condensation will also more and more fully vanish, and the density of the cold rod as a consequence again decrease. Now, it is exceedingly remarkable and significant that the electrical effects due to the annealing of a glass-hard steel rod, enormous as they are, vanish almost entirely after the temperature of the annealing bath exceeds 300° to 400° , that, is at a temperature at which the density of a homogeneous hot rod is the same as the density of an identical cold glass-hard rod,⁸² or, in other words, very nearly at the temperature t^0 just discussed.⁸³ Magnetic effects, however, as will be shown elsewhere, are still very marked for rods annealed at temperatures higher than t^0 . This is in conformity with the hypothesis of residual surface condensation, because magnetic phenomena are so largely dependent on the external layers of a rod. Finally, the actual existence of a maximum of density for rods annealed at temperatures near t^0 has been experimentally shown by Fromme.⁸⁴

(4). With these remarks, however, the subject is by no means fully exhausted, even so far as our present purposes go. It is easily conceivable that a rod at 400° may be brought into a condition of strain (strain of hardness) which bears the same relation to an identical homogeneous rod at 400° that an ordinary glass-hard rod does to an identical cold soft rod. We believe, however, that the viscosity of the hot rod is too insignificant to admit of the permanent retention of more than reduced intensities of stress, no matter how much of the strain peculiar to temper may by some ideal means⁸⁵ have been imparted to it. In other words, suppose that a sufficient and very great intensity of

⁸² Cf. pp. 90-93.

⁸³ The condensed layers of the rod being thin in comparison with the rarefied parts.

⁸⁴ Fromme: l. c., p. 355.

⁸⁵ To form a definite conception of an ideal process of tempering like the one in question, suppose the observer to have in control a set of forces, by aid of which he is able to move each of the molecules of a (soft) steel rod into such positions that the rod, as a whole, experiences a strain of glass-hardness of very great intensity. When this characteristic distribution of molecules within the volume of the (now) hard rod has been effected, let the action of the said forces be discontinued and the molecules

the strain in question is imparted both to an iron and to a steel rod of the same dimensions. When the tempering influence has ceased, the steel rod will have retained a phenomenal amount and exhibit glass-hardness. The iron rod, on the contrary, will have lost nearly the whole of it. Analogous to the latter, the steel rod when at 400° , no matter how much stress may be imparted to it, will permanently retain no more at 400° than the small amount which is consistent with the definition of viscosity above given.⁸⁶ The present consideration, therefore, culminates in an experimental inquiry which may be formulated thus: Will a steel rod, if chilled from a given temperature in red heat in a liquid at any temperature below t^0 , and subsequently annealed by an exposure to t^0 , indefinite as regards time, always exhibit the same final intensity of stress or thermo-electric hardness—barring of course all secondary effects, such as are due to decarburization, etc.

THE PHENOMENON OF GLASS-HARDNESS DISCUSSED FROM THE CHEMICAL AND FROM THE MECHANICAL STANDPOINT.

Chemical interpretation.—We now proceed to the discussion of the effects of sudden chilling on steel. If we endeavor to explain the known phenomena mechanically, we encounter two grave difficulties. In the first place, we fail to find any obvious reason why the hardness of a chilled rod is not, as Chernoff⁸⁷ discovered, a uniformly continuous function of the temperature of the rod before sudden cooling. In the second place, the important function of carbon in the process of tempering, and the necessary presence of this element in steel if the effects of sudden cooling are to be permanent, is not easily discernible. Both these apparently weak points of the mechanical theory may be very easily explained chemically. It is only necessary to suppose that a certain high temperature must be reached before the uncombined carbon of soft or annealed rod is again either converted into the combined form or is dissolved.⁸⁸ That such a temperature would lie, at lowest, in the

left to themselves. Then will the excess of stress gradually disappear, until, through infinite time, the intensity of strain which the given rod under the given circumstances of temperature of itself can just permanently retain, is reached. The (hard) rod is now in a condition of stable molecular equilibrium. The close analogy between this ideal method of imparting temper and magnetization is at once apparent.

⁸⁶ Cf. p. 95, (1).

⁸⁷ Chernoff: Vortrag geh. in der Russ. Tech. Gesell., April u. Mai, 1878; cf. Jeans, op. cit., p. 644-7. A reprint of Chernoff's lecture kindly sent by the author showed us that Chernoff was the first to discover the remarkable phenomenon in question. Our own experiments, made independently of Chernoff and shortly after him, led to the same result, both as regards mechanical and thermo-electric hardness. (Cf. Barus; Wied. Ann., VII, p. 405, 1879; Strouhal and Barus; Wied. Ann., XI, p. 946, 1880.)

⁸⁸ Cf. Karsten's theory on the existence of a "polycarburet," for instance, in Percy-Wedding, op. cit., p. 167; Jeans, op. cit., p. 646; etc.

region of red heat is immediately probable. Sudden cooling from temperatures below this critical value, in so far as carbon would remain undissolved or uncombined, could not impart hardness to steel, but would merely anneal it the more thoroughly—which is actually observed. It is particularly to be noted here, moreover, that, according to Jeans, in the cementation process iron will not absorb carbon until a certain definite high temperature has been reached.

Physical interpretation.—(1) The first of the above-mentioned difficulties encountered by a mechanical theory must here be discussed with greater detail. The phenomenon is not without remarkable physical analogies. Cumming,⁸⁹ for instance, and after him others, called attention to the very sudden expansion exhibited by iron at a certain temperature in red heat. Tait⁹⁰ signalizes the abnormal thermo-electric behavior of iron under the same circumstances. Finally, the discovery due to Gore,⁹¹ which Baur⁹² has recently studied with considerable detail, is to be cited here, viz., that the temporary magnetism of saturated iron at the said temperature suddenly vanishes from a foregoing very large value. There appears to be little reason to doubt that all of these phenomena are different manifestations of the same cause.⁹³

(2) If, now, we bear in mind that a glass-hard rod has retained a very large part of the increment of volume due to the heat expansion, at the temperature from which it was chilled; that furthermore very rapid cooling is the necessary condition of the appearance of glass-hardness; then the remarks just made at once suggest the inference that Cumming's phenomenon plays a very important part in the process of tempering. It would follow, furthermore, that the said phenomenon must first fully have appeared if sudden cooling is to be accompanied by hardness. Hence the necessity of a critical temperature. Here, therefore, we encounter the first difference between iron and steel on the one hand, and all other metals and alloys on the other (these being without the said phenomenon), as regards conditions favorable to the production of hardness by chilling.

(3) The difference between iron and steel, however, appears even at ordinary temperatures whenever both materials are subject to the same kind of stress. If, for instance, we expose two like rods, one of iron and

⁸⁹ Cumming: Cf. Tait, l. c. Gore: Proc. Roy. Soc., XVII, 260, 1869.

⁹⁰ Tait: Trans. Roy. Soc., Edinburgh, XXVII, 1872-73, p. 125; Proc. R. S. E., VIII, p. 32, 1872-73.

⁹¹ Gore: Phil. Mag., (4), XXXVIII, p. 59, 1869; *ibid.*, XL, p. 170, 1870.

⁹² Baur: Wied. Ann., XI, p. 408, 1880.

⁹³ Tait refers the sinuous and broken character of the iron line in his thermo-electric diagram to Cumming's phenomenon. Gore, and more thoroughly Baur, ascribe the anomalous behavior of temporary magnetism at red heat to the same cause, in both cases attributed to Gore. The same irregular results would probably recur in the variation of electrical conductivity on passing the temperature in question. The method of experimentation adopted by Benoit (l. c.) led him to overlook this. With the discovery of Chernoff these interesting analogies are enriched by a new fact.

one of steel, to the influence of the same sufficiently intense magnetic field, the steel rod, after withdrawal, is found to have retained a very considerable part of its original magnetism permanently, whereas the iron is comparatively unmagnetic. Analogously we find that, although both iron and steel possess the essential property of sudden expansion at red heat discovered by Cumming, steel after sudden cooling has retained a phenomenal amount of the peculiar and characteristic strain accompanying hardness, while iron remains nearly soft and comparatively homogeneous. It appears, therefore, that the effect of sudden cooling on steel also admits of a physical explanation.

Physical and chemical changes simultaneous.—There is one other consideration to be added here. If we compare the difference between steel and iron as regards their power for the retention of a given mechanical strain, with the respective retentive properties of steel at different temperatures, we may readily infer that under all circumstances the absolute amount of combined carbon in iron or steel is the essential factor. From this standpoint every gradually progressive change of strain from any original to any final value is to be looked upon as a physical phenomenon; the fundamental cause of such gradual change of strain, in other words the cause for the necessary change of viscosity, is to be regarded as only dependent on temperature in such measure as temperature itself determines the ratio of combined to uncombined carbon; hence, also, the amount of combined carbon in the steel rod. Here, therefore, the thermo-electric hardness of a rod annealed for an indefinite length of time at t degrees is an indication of the amount of combined carbon in the rod at this temperature.

EXPERIMENTS WITH MALLEABLE CAST-IRON.

Above inferences not decisive.—Endeavoring to review the above matter with the object of obtaining data for the discrimination between the physical and the chemical features of the process of tempering, we fail to find criteria sufficiently decisive to enable us to draw our inferences satisfactorily. We are induced even to acknowledge that there exists a remarkably intimate relation between the two methods of interpreting the various phenomena; for not only are we able to explain even the more important details both from the chemical and the physical standpoint, but the development of either hypothesis continually suggests new means for the development of the other.

Electric behavior of malleable cast-iron.—At this stage of our research it appeared probable that further and perhaps critical information might be obtained from a study of the electrical behavior of different species of cast-iron. We commenced our inquiry with an examination of what

is known as "malleable cast-iron,"⁹⁴ a material which from its exceptional position in the series of iron-carburets seemed particularly well adapted for the elucidation sought. This product is tough and tenacious, though imperfectly malleable in the soft state, but after sudden cooling from red heat becomes almost as hard and certainly quite as brittle as hard steel. Forquingnon⁹⁵ has shown that it is distinguished from steel, chemically, by the relatively very large amount of graphite which it contains. We were fortunate in obtaining rods of malleable cast-iron from M. E. Hartmann, in Würzburg.

The results of our measurements of thermo-electric power are given in the following table (42) on a plan identical to that adopted above for alloys. The rods were examined in three states of hardness, viz., in the commercial condition in which they reached our hands, then immediately after sudden chilling, finally after thorough annealing (softening) by slow cooling from red heat:⁹⁶

TABLE 42.—*Thermo-electric power of malleable cast-iron.*

Rods.	<i>t</i>	<i>T</i>	ϵ observed.	ϵ calculated.	Diff.	<i>a</i>	<i>b</i>
ROD No. 1.							
	C.	C.	microvolt.	microvolt.			
Original condition	18.3	79.7	-57.3	-57.2	-0.1	} +0.45	-0.014
	18.4	68.8	-39.4	-39.2	-0.2		
	18.5	58.3	-25.0	-25.1	0.1		
	18.6	47.4	-13.4	-13.7	0.3		
	18.7	38.2	-7.0	-6.8	-0.2		
Chilled hard.....*	15.7	59.0	-81.6	-80.8	-0.8	} -0.90	-0.013
	15.7	51.2	-62.5	-62.7	0.2		
	15.7	43.4	-45.6	-46.2	0.6		
	15.7	36.7	-33.0	-33.2	0.2		
	15.7	30.1	-21.8	-21.6	-0.2		
Soft	17.9	86.1	-69.8	-68.5	-1.3	} +0.30	-0.013
	17.9	77.2	-52.3	-53.0	0.7		
	17.9	66.5	-36.3	-36.9	0.6		
	17.9	53.9	-21.5	-21.6	0.1		
	17.9	43.1	-11.9	-11.7	-0.2		
ROD No. 2.							
Original condition	16.8	75.9	-14.3	-13.2	0.9	} +0.98	-0.013
	16.9	66.3	-7.1	-6.4	-0.7		
	17.0	56.1	0.0	+ 0.1	-0.1		
	17.0	45.2	+ 3.7	+ 4.2	-0.5		
	17.1	37.2	+ 5.5	+ 5.1	0.4		
Chilled hard.....	12.0	53.9	-25.5	-24.4	-1.1	} +0.37	-0.014
	12.2	46.3	-15.4	-16.3	0.9		
	12.3	40.9	-11.1	-11.5	0.4		
	12.4	35.5	-7.6	-7.4	-0.2		
	12.5	30.3	-4.6	-4.4	-0.2		
Soft	18.2	86.1	-43.7	-43.8	0.1	} +0.72	-0.013
	18.2	72.3	-25.5	-25.2	-0.3		
	18.3	55.5	-9.5	-9.1	-0.4		
	18.3	45.1	-2.4	-3.0	0.6		
	18.3	35.1	+ 0.1	+ 0.3	-0.2		

⁹⁴ Cf. Perry-Wedding, *op. cit.*, p. 143.

⁹⁵ Forquingnon, *l. c.*, p. 536.

⁹⁶ The usual process of surrounding the rods with ferro-ferric oxide in gas-pipe (closed), then heating the latter to redness in a charcoal furnace, in which the tube is left until the fire is completely extinguished, being adopted.

TABLE 42.—Thermo-electric power of malleable cast iron—Continued.

Rods.	t	T	e observed.	e calculated.	Diff.	α	β
Rod No. 3.							
	C.	C.	microvolt.	microvolt.			
Original condition.....	16.1	67.8	7.6	6.8	0.8	1.00	-0.070
	16.2	62.0	8.3	8.6	-0.3		
	16.2	50.3	9.6	10.6	-1.0		
	16.3	43.7	10.5	10.4	0.1		
	16.3	37.3	9.5	9.2	0.3		
Chilled hard	17.8	58.2	-22.9	-22.1	-0.8	0.73	-0.017
	17.9	51.1	-14.0	-14.4	0.4		
	17.9	44.9	-8.8	-9.0	0.2		
	17.9	37.9	-4.2	-4.2	0.0		
	17.9	31.2	-1.4	-1.3	-0.1		
Soft	18.9	80.2	-31.0	-29.6	-1.4	1.15	-0.016
	18.9	66.1	-10.8	-12.0	1.2		
	18.9	53.1	-0.6	-1.3	0.7		
	18.9	42.1	+2.8	+3.3	-0.5		
	18.8	33.2	+4.1	+4.1	0.0		

The following and final tables (43) contain our results for the specific resistance of malleable cast iron in each of the three states—commercial, chilled hard, annealed soft (at red heat). In column third is given the actual resistance per meter of rod at the temperature t . The sections in cm^2 are found under q . The specific resistances at t and 0 degrees are arranged under s_t and s , respectively, while the intermediate column α contains the temperature-coefficients for this reduction:

TABLE 43.—Electrical resistance of malleable cast iron.

Rod.	Remarks.	W l _m	t	q	$\frac{\text{cm}}{\text{cm}^2} \text{ } ^\circ\text{C}$	α	$\frac{\text{cm}}{\text{cm}^2} \text{ } ^\circ\text{C}$
		ohm.	C.	cm^2	microhm.		microhm.
1	Original condition.....	0.0274	15.5	(0.308)*	26.0	0.004	24.4
	Chilled hard	377	11.5	(0.302)*	34.8	0.004	32.7
	Soft	290	14.5	(0.290)*	24.4	0.004	23.0
2	Original condition	0.0262	15.5	(0.307)*	24.8	0.004	23.3
	Chilled hard	323	11.5	(0.300)*	29.2	0.004	27.9
	Soft	285	14.5	(0.296)*	25.0	0.004	23.6
3	Original condition.....	0.0262	15.5	(0.308)*	24.1	0.004	22.6
	Chilled hard	316	11.8	(0.297)*	27.9	0.004	26.6
	Soft	290	14.5	(0.290)*	24.4	0.004	23.0

In the following digest the main data obtained for malleable cast-iron are given in more perspicuous form. Δa contains the range of variation of the thermo-electric constant a from soft to hard. Δs has the same signification as regards specific resistance:

TABLE 44.—Thermo-electric power and specific resistance of malleable cast-iron.

Rod number.	Thermo-electric power (a).		Specific resistance.		Δa	Δs
	Soft.	Hard.	Soft.	Hard.		
1.....	+0.80	-0.90	23.0	32.7	-1.20	+9.7
2.....	+0.72	+0.37	23.6	27.9	-0.85	+4.3
3.....	+1.15	+0.73	23.0	26.6	-0.42	+3.6

Decisive character of the evidence.—The first striking feature of the last set of results is the slight thermo-electric difference between the malleable cast-iron rods and silver. Hence the large values of thermo-electric hardness corresponding to the large values of specific resistance.

Far more remarkable, however, are the almost insignificant variations (Δa and Δs) produced by sudden cooling. Here, therefore, we have a valuable example of an iron-carburet in which the interval of mechanical hardness due to tempering; i. e., the difference of mechanical hardness between hard and soft is very great, whereas the corresponding change of the electrical constants scarcely reaches the electrical difference between "blue annealed" and "soft" for steel. In this respect, therefore, these measurements have critical value. It follows that the mechanical hardness possessed by chilled steel cannot be the only or even the principal cause of the enormous variation of the electrical constants; that the said cause of these variations must be sought in the secondary phenomena which accompany the presence of hardness; that they are therefore very probably due to the strains manifesting themselves, as a whole, in the volume expansion of hard steel.

This important deduction is further substantiated by certain experiments made with cast-iron by Joule.⁹⁷ His results showed that cast-iron in the white, hard condition is thermo-electrically nearest antimony; in the black,⁹⁸ graphitic condition, however, nearest bismuth. All other samples of cast iron examined occupied thermo-electric positions between these limits. If, therefore, the shifting of thermo-electric position produced by sudden chilling were to be ascribed to the conversion of uncombined into combined carbon, hard steel, like white cast-iron, would lie nearest antimony, soft steel nearest bismuth, whereas the actual positions of steel in these two extreme states of hardness is just the reverse of this. Hence it would follow, again, that the change of thermo-electric power of steel due to tempering must be referred to the increase of volume simultaneously experienced. In striking accordance with this inference are the results of Forquignon:⁹⁹ "*Le fonte malléable se distingue de l'acier par ses faible allongements et sa forte teneur en graphite.*" It appears, therefore, that here again the absence of marked volume increase is the concomitant of the absence of marked electrical variation.

If we add to these deductions the remarks made in pages 89, 95, and 99, we arrive at the following final result: The existence of the peculiar strain accompanying hardness in steel is the cause of electrical effects so enormous that such additional effects which any possible change of carburization may involve can be wholly disregarded, and all electrical results interpreted as due solely to variations in the intensity of the said strain.

⁹⁷Joule: Phil. Trans., 1859, I, p. 97.

⁹⁸That is, black at the surface of fracture, known to be rich in graphite.

⁹⁹Forquignon, l. c., p. 536.

CHAPTER IV.

ON THE THERMO-ELECTRIC EFFECT OF MAGNETIZATION.

Earlier results.—A number of facts go to prove that the molecular structure of an iron-carburet is materially affected both by the intensity and by the kind of magnetization which it receives. We know, moreover, from experiments of Joule,¹⁰⁰ Wertheim,¹⁰¹ Mayer,¹⁰² that the existence of magnetism in a bar exerts a stress bearing some analogy to a pull in the direction of the magnetic axis. This strain seems to be an inseparable concomitant of the magnetic quality. We therefore infer at once that if two identical steel rods be magnetized to different intensities, their original thermo-electric powers will have changed; that, moreover, the increments of this quantity in the two cases, in accordance with the difference of magnetic state premised, will be unequal. Similar remarks possibly apply to other physical constants of steel, in particular to its electrical conductivity. With regard to the latter, the results of earlier observers are either unsatisfactory or discordant.¹⁰³ The experiments of Beetz¹⁰⁴ furnish the first evidence of a decisive character. This physicist found that the resistance effect of longitudinal magnetization is an increment of from 0.03 per cent. to 0.06 per cent.; that in the case of transverse magnetization, however, no variation (greater than 0.0005 per cent.) is appreciable. Beetz's result has been corroborated and supplemented by experiments of Auerbach,¹⁰⁵ who maintains that while the specific resistance of hard steel increases continuously from the longitudinally to the circularly magnetized state, soft iron and soft steel possess a minimum of resistance when unmagnetic.

The discovery of a thermo-electric effect of magnetization is due to Sir W. Thomson,¹⁰⁶ and his experiments furnish the only results on the subject which have thus far been obtained. He found that an iron wire in the longitudinal or in the transversely magnetized state is thermo-electrically positive or negative,¹⁰⁷ respectively, when compared with the

¹⁰⁰ Joule: *Phil. Mag.*, XXX, pp. 76, 225, 1847.

¹⁰¹ Wertheim: *Ann. d. Chim. et de. Phys.* (3), XXIII, p. 302, 1848.

¹⁰² Mayer: *Phil. Mag.* (4), XLVI, p. 177, 1873.

¹⁰³ Cf. digest and partial discussion in Wiedemann's *Galvanismus*, IIa, p. 586 (ed. 1874).

¹⁰⁴ Beetz: *Pogg. Ann.*, CXXVIII, p. 202, 1866.

¹⁰⁵ Auerbach: *Wied. Ann.*, V, p. 289, 1878.

¹⁰⁶ Thomson: *Phil. Trans.*, III, p. 722, 1856.

¹⁰⁷ In Seebeck's sense. See preface.

same wire in the unmagnetic state; that is, there would be a thermo-current from transversely magnetic to unmagnetic through hot, or from unmagnetic to longitudinally magnetic through hot.

Relative electrical effects of hardness and magnetization.—These facts have an immediate bearing on the question in how far the method for the measurement of hardness which we employed in the case of unmagnetic rods is to be modified when we deal with magnets. For it is obvious, if the hardness of a steel rod is to be expressible in terms of its thermo-electric power, that magnetization, in so far as it produces no appreciable change of the mechanical quality, must to an equal extent be without influence on the value of its electrical equivalent.

The effect of transverse and of circular magnetization on the specific resistance is not distinctly marked. Beetz, *l. c.*, obtained no indication whatever. We are justified in accepting a similarly small interval of variation for the thermo-electric power, although Thomson, *l. c.*, was able to adduce conclusive experimental proof of its existence. In its bearing on the especial purposes of the present series of papers, this effect is, however, of secondary importance; for which reason, and in view of the difficulties with which an exact measurement would be surrounded, we determined to neglect it in favor of the much more pronounced phenomenon now to be considered.

It is the evaluation of the electrical effect of longitudinal magnetization, therefore, which is carefully to be essayed. As regards the specific resistance, the results of Beetz furnish the datum of only about a half-tenth per cent. for iron in the most favorable case. Now the resistance effect of glass-hardening is as high as 300 per cent. It is obvious, therefore, that where the specific resistance is used for the definition of hardness of steel, the effect of magnetization is thoroughly negligible, since for steel it will probably fall even below the small value for iron; particularly so where permanent magnetism is alone of interest. Consequently this mode of measurement of hardness may be immediately applied to steel irrespective of its magnetic state.

In considering the thermo-electric behavior of steel in its dependence on magnetization, the following striking peculiarity is conspicuous at the outset. When the simultaneous variation of thermo-electric power and specific resistance is produced by tempering, the result is such that steel for continually increasing resistance moves constantly toward greater thermo-electrically negative values. When the simultaneous variation in question is produced by magnetization, however, a positive increment of resistance (Beetz) corresponds to a shifting of steel towards thermo-electrically positive values (Thomson). This at once points out a radical difference between these phenomena, a difference, however, which might have been anticipated both from the utter dissimilarity of the strains, as well as from the fact that we necessarily deal with steel only in the first case, but with iron and steel (soft) respectively, in the

second—where, moreover, the behavior of soft and of hard steel is not even qualitatively the same (Auerbach).

The magnetic result admits of the following interpretation. It has been stated that one of the results of magnetization is elongation in the direction of the magnetic axis and contraction at right angles to it in such proportions as leave the volume of the iron unchanged (Joule). In this respect the stress is analogous to a pull. Now, Thomson discovered in the one case a current from transversely magnetized to longitudinally magnetized iron through hot; in the other a current from transversely strained to longitudinally strained iron through hot. Possibly, therefore, we have in hand more than an incidental coincidence. It is to be noted that both results apply for elongation within the elastic limits.¹⁰⁸

Method of experimentation.—Thomson's results are qualitative. For our purposes, however, quantitative results are a necessity. With the object of deriving these the following experiments were made. The disposition of apparatus is diagrammatically given in Fig. 14. A soft iron

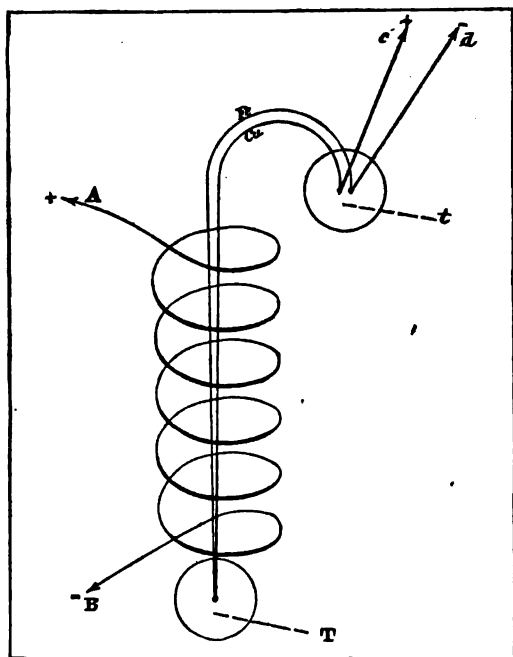


FIG. 14.—Disposition of apparatus.

wire about 0.08 centimeter thick and 40 centimeters long, the ends of which had been fastened to long terminals (*c*, *d*) of copper wire, was

¹⁰⁸ Thomson, *l. c.*, pp. 712, 713. Cohn, *Wied. Ann.*, VI, p. 385, 1-79. Beetz (*Pogg. Ann.*, CXXVIII, p. 193, 1866) remarks that the resistance effect of magnetization is probably to be referred to the occurrence of the magnetic strain, and in so far anticipates the above statement. But he possesses no direct evidence.

thrust through a helix (AB) together with one of the copper wires, and fixed in its axis. At each of the ends of the helix, and as near its center as possible, a doubly tubulated spherical receiver, containing petroleum at the temperatures t and T , respectively, was placed. These receivers contained the junctions of the thermo-element (copper-iron). In other respects the disposition and method of measurement was the same as that employed in the previous chapter II, and the reader desiring further information is referred thither.¹⁰⁹

The helix in question had a length of 22.3 centimeters, contained ten layers, each with about 55 windings of thick copper wire 0.3 centimeter in diameter.

A Siemens dynamo-electric machine was at our disposal as a source of strong current, the intensity of which, obtained by the aid of a large tangent compass, under the given circumstances proved to be

$$i = 3.12 \frac{g^{\frac{1}{2}} \text{ cm}^{\frac{1}{2}}}{\text{sec}}$$

Let $2a$ be the length, r the radius of a given layer of the helix, n the number of turns of wire in the layer, $2b$ the length of the rod to be magnetized. Then will the magnetizing force on the axis of the helix and at a distance b from its center be

$$X_b = \frac{\pi n i}{a} \left[\frac{a+b}{\sqrt{(a+b)^2 + r^2}} + \frac{a-b}{\sqrt{(a-b)^2 + r^2}} \right]$$

and the mean magnetizing force of this layer referred to the given length ($2b$) of wire

$$X = \frac{\pi n i}{a b} \left[\sqrt{(a+b)^2 + r^2} - \sqrt{(a-b)^2 + r^2} \right]$$

The following are the data describing the field actually used:

$$\Sigma X_b = 35$$

$$\Sigma X = 528$$

$$\frac{g^{\frac{1}{2}}}{\text{cm}^{\frac{1}{2}} \text{ sec}}$$

It is unfortunate that the conditions of a more uniform field could not be secured. But in view of the very large central intensities ($X_0 = 940$), the belief is warranted that the maximum of magnetization must at least have been very nearly attained. A uniform field of the intensity, 130 to 140, is usually regarded as sufficient to magnetically saturate iron. Our mean value (528) is about four times as large.

The actual measurement of the influence of magnetization on the thermo-electric power of iron was made in such a way that two separate series, each of five observations of electro-motive force and temperature for the rod free from magnetism (*i. e.*, without magnetizing current), included a single series of the same number of observations for the magnetized rod (*i. e.*, with current). The thermo-electric constants of the first and third series were therefore to be regarded as identical,

while those of the second would differ from them by an amount equivalent to the magnetic effect to be measured. In order that all direct action of the helix on the galvanometers or parts of the circuit might be avoided, the former with its attached thermo-element was placed at a great distance (100 feet) from the latter. These remote parts of the set of apparatus being connected by copper wire of a given kind, no discrepancies due to extraneous thermo-currents in the connections were to be apprehended. On all these points we satisfied ourselves by special tests.

Results.—(1) The results of the three series of observations in question are contained in the following table. If e be the electro-motive force for the temperatures t and T of the junctions, we have

$$e = a(T - t) + b(T^2 - t^2) \quad \dots \quad (1)$$

a formula to be applied to the three cases. We proceeded as follows: Having calculated the constants a and b for the series of observations I and III (unmagnetic iron-copper) by the method of least squares, the mean of the two values of each was taken, and together with the temperatures T and t belonging to the series II, was used in deducing values of e for this series, by the aid of formula (1). In the table the latter are given in parentheses. They are therefore such as would hold for the element unmagnetic copper-iron under circumstances identical with those in which the element magnetic copper-iron was actually placed.

TABLE 45.—*Thermo-electric power of magnetic and unmagnetic iron.*

	t	T	e observed.	e calculated.	Diff.	
	°C.	°C.	microvolts.	microvolts.		
I. Iron wire not magnetic ¹	15.5	71.9	564.1	564.0	+0.1	$a = 11.880$ $b = -0.0213$
	15.4	60.1	458.9	458.3	-1.4	
	15.3	56.0	384.7	383.3	-1.4	
	15.3	39.7	261.7	260.8	+0.9	
	15.2	31.0	171.8	171.9	-0.6	
II. Iron wire magnetic.....	15.1	88.6	674.2	(669.3)	+4.9	
	15.0	72.5	578.8	(575.5)	+3.3	
	15.0	58.2	448.9	(445.5)	+3.4	
	15.0	46.2	332.5	(329.6)	+2.9	
	14.9	35.9	229.5	(226.5)	+3.0	
III. Iron wire not magnetic.....	14.8	90.8	733.8	732.3	+1.5	$a = 11.883$ $b = -0.0211$
	14.8	79.3	635.9	637.2	-1.3	
	14.8	67.8	536.2	536.3	-0.1	
	14.7	54.0	408.8	409.2	-0.4	
	14.7	45.0	325.7	325.2	+0.5	

¹ Electro-motive force relatively to copper (given sample), as zero, in each of the three cases.

An inspection of the column of differences proves conclusively that longitudinally magnetic iron wire is thermo-electrically more positive than iron free from magnetism. We have, therefore, a corroboration of Thomson's result.

• Nevertheless, the differences in question are small, and if we compare them with the set of values for the series I and III in the same column we infer that they must be largely distorted by incidental errors. It appears, therefore, that the observations are not adequately exact for

the calculation of the constants of the element magnetic-unmagnetic iron with the desirable accuracy, though they do furnish a good estimate of their value.

(2) For this reason we made a second set of experiments differing from the above in so far as much greater intervals ($T-t$) of temperature were chosen. T and t being kept as nearly constant as possible, measurements of e for the magnetized and unmagnetized state of iron were alternately made. Supposing the resistances of Bosscha's zero method to have been so adjusted that for given values of T and t and unmagnetic iron no current was appreciable in the galvanometer, it was found that a permanent deflection at this instrument immediately occurred on closing the magnetizing circuit through the helix, of such a kind as to indicate an *increase* of thermo-electromotive force. That this effect is of purely thermo-electric origin, and is not to be directly ascribed to extraneous influences, follows conclusively from the regularity of increase of e with increasing values of T . To produce different but temporarily constant values of the latter quantity the boiling point of water and of aniline and the melting point of lead were found serviceable.

The table below contains mean values of electro-motive force and temperature, the results being derived from a great number of measurements of e , with alternately open and closed magnetizing current, for each pair of values of T and t . The differences between the values of e corresponding to magnetic and unmagnetic iron respectively, enable us to calculate the constants a and b for the thermo-couple composed of two identical iron rods, one of which, however, is magnetically saturated, the other free from magnetism.

TABLE 46.—*Thermo-electric power of magnetic and unmagnetic iron.*

	t	T	e observed.	e calculated.	Diff.	
	°C	°C	microvolts.	microvolts.		
I. Iron wire, not magnetic ¹	16.5	99.3	785	787	-2	$a = 12.40$
	15.4	184.2	1256	1251	+5	$b = -0.0240$
	17.	328.	1173	1178	-5	
II. Iron wire, magnetic ¹	16.5	99.2	788	790	-2	$a = 12.43$
	15.4	184.2	1267	1261	+6	$b = -0.0248$
	17.	328.	1190	1204	-5	
Thermo-electric couple: magnetic-unmagnetic iron ²	16.5	99.2	4.0	4.2	-0.2	$a = +0.035$
	15.4	184.0	11.3	10.5	+0.8	$b = +0.00014$
	17.	328.	25.4	25.8	-0.4	

¹ Thermo-electromotive force relatively to copper (given sample) as zero.

² Thermo-electromotive force relatively to unmagnetic iron as zero.

Value of the effect.—The thermo-electric effect of magnetization, as given by the constant a , is therefore $+0.035$. The corresponding effect due to tempering—*i. e.*, the difference between the constants a for the soft and for the glass-hard state—attains values as high as 13.0. Hence,

even if the behavior of iron and steel were qualitatively the same—an unfavorable supposition not in accord with Thomson's observations—the increment of thermo-electric power resulting from complete saturation would only amount to a few tenths per cent. of the thermo-electric interval between soft and glass-hard steel. But in our experiments we shall have to do with permanent magnetism only, whence it follows that the discrepancy will be reduced to a much smaller value. We conclude that the thermo-electric hardness of a steel rod is practically *independent* of its magnetic state.

A remark on the general character of the strains met with in this chapter is in order here:

(1.) In the case of steel (cylindrical rods) hardened by tempering, we observe a dense external shell surrounding an abnormally rare core, in such a way that greatest intensity of stress is exerted in the radial direction; *i. e.*, at right angles to the axis of figure. Tempered steel has been shown to be thermo-electrically negative towards soft steel.

(2.) In the case of steel hardened by drawing through a wire-iron, we observe a compressed external shell (though of far lesser density than in the first case) surrounding a slightly rarified core, in such a way that greatest intensity of stress is exerted in an axial direction. Hard-drawn steel is thermo-electrically positive toward soft steel.¹¹⁰

(3.) If an iron wire is longitudinally stretched and the deformation temporary, then the strain, so far as its electrical indications are concerned, is similar to the magnetic strain in iron.

¹¹⁰Magnus: Pogg. Ann., LXXXIII, p. 469, 1851.

CHAPTER V.

ON THE INFLUENCE OF HARDNESS ON THE MAXIMUM OF MAGNETIZATION WHICH THIN CYLINDRICAL STEEL RODS OF DIFFERENT DIMENSIONS PERMANENTLY RETAIN.

PLAN AND PURPOSE OF THE PRESENT EXPERIMENTS.

Earlier results.—The relation existing between the magnetic properties and the state of hardness of steel has been made the subject of a very large number of investigations.¹¹¹

Dimension-ratio and hardness.—After the apparently discordant results of J. Müller, Plücker, and Wiedemann, on the one hand, and Hansteen and Lamont, on the other, had been interpreted by Ch. Ruths in a very thorough investigation—subsequently corroborated by Fromme—the present question may be said to have been answered in so far as the practically important factor, the ratio of dimensions of the material experimented upon, is concerned. It was herewith conclusively proven that both temporary¹¹² and permanent magnetism show a totally different kind of dependence on the state of hardness of steel when the saturated rods are long than when they are short. On the basis of these researches our knowledge of the practically more important permanent magnetism, more particularly the maximum possible for a given cylindrical steel rod, may be summarily stated as follows:

So long as the ratio of length to diameter is smaller than a certain

¹¹¹ Digests of the earlier papers may be found in J. Lamont, *Handbuch des Magnetismus*, p. 249, 1867; G. Wiedemann, *Galvanismus*, IIa, p. 340, 1874. Among the more recent publications (since 1876) the following are especially to be mentioned: Ch. Ruths, *Inaug. Dissertation*, p. 34, Darmstadt, 1874; Ch. Ruths, *Ueber den Magnetismus weicher Eisencylinder*, etc., Dortmund, 1876; J. M. Gangain, *Comptes Rend.*, LXXXII, p. 144, 1876; C. Fromme, *Göttinger Nachrichten*, p. 157, 1876; Trève et Durassier, *Comptes Rend.*, LXXXII, p. 145, 1876; A. v. Waltenhofen, *Dingler's Journal*, CCXVII, p. 357, 1876; *ibid.*, CCXXXII, p. 141, 1879; Gray, *Phil. Mag.* (5), VI, p. 321–332, 1878; A. Righi, *Beiblätter*, V, p. 62, 1881; W. Metcalf, *Beiblätter*, V, p. 895, 1881; A. Pictet, *Arch. de Gen.* (3), VI, p. 113–125, 1881.

The remarks made in this and the following chapters were originally published in the *Verhandl. der phys.-med. ges. zu Würzburg*, N. F. XVII, p. 19, 1882. The present paper differs from these in form, the observations having been reduced throughout to the current absolute electromagnetic units, and by containing a large number of experiments made since the date of original publication. It will be found that the latter have added essential corroboration to the inferences drawn. The reduction in question, presupposing a knowledge of the contents of Chapter I, has not until lately been feasible.

¹¹² The terms “permanent” and “temporary” as used here have the signification proposed by G. Wiedemann in *Beiblätter* I, p. 67, 1877.

limiting value, apparently characteristic of the material chosen, cylindrical rods are capable of retaining a greater intensity of magnetism permanently when in the glass-hard than when in the annealed state; but after the ratio in question increases to values above this limit, hard rods are overtaken in this respect by the yellow annealed; these in turn by the blue annealed. Soft rods, *cæteris paribus*, usually retain more magnetism than hard or annealed rods of the same dimensions, except when the ratio of axes is small.

Carburation.—The results in hand for the specific magnetic effect of carburation are even more unsatisfactory. We possess at best cursory or isolated data, due to Barlow,¹¹³ Müller,¹¹⁴ Jamin,¹¹⁵ v. Waltenhofen,¹¹⁶ Pictet.¹¹⁷ To our knowledge the only attempt at a systematic research with reference to the effect of carburation was made by Trève and Durassier.¹¹⁸ But the results of these observers are far from being even approximately complete. They are, moreover, seriously obscure, because insufficient attention is paid both to hardness and dimensions.

Taken as a whole, therefore, the work done, however valuable, can serve for orientation only. It is of the nature of a mere estimate. The full and minute analysis must introduce all those complications of a metallurgical kind which render the term "steel" itself indefinite. In this place the effect of carburation cannot even be discussed with advantage. It will, therefore, be waived, to be resumed in Chapter VII of the present memoir, where we shall have occasion to review the physical characteristics of the iron carburets in general.

Critical discussion.—Returning from this digression to a discussion of the magnetic effect of the hardness and of the dimensions of steel rods, we find it undeniable, although the main features of the subject may be said to be roughly outlined, that the information gained is almost intangibly vague and unsatisfactory. In fact, the solution is at most a qualitative one. The data of the above researches, in other words, do not enable us to trace the continuous change of magnetic intensity of thin saturated steel rods, considered for the time being as a function of a single independent variable hardness only—the steel passing from an initial (soft) to a final (hard) state through every intermediate state, dimensions and carburation being regarded as parameters. And yet it is only from results of this character that an intelligent insight into these complicated phenomena can be obtained.

There are two difficulties which have thus far stood in the way of more exact research in this direction. The first of these was the want of a sufficiently sensitive method for the discrimination between degrees of

¹¹³ Barlow: Phil. Trans. p. 117, 1822.

¹¹⁴ Müller: Pogg. Ann., LXXXV, p. 157, 1852.

¹¹⁵ Jamin: Comptes Rend., LXXVII, p. 80, 1873.

¹¹⁶ V. Waltenhofen: Pogg. Ann., CXXI, p. 431, 1864.

¹¹⁷ Pictet: Arch. de Genève (3), VI, p. 113, 1881.

¹¹⁸ Trève et Durassier, Mondes, XXVIII, pp. 567, 667, 1875.

hardness. The estimate furnished by the oxide tints,¹¹⁹ if indeed rigidly reliable, is much too crude. The same would be true of any other of the more current methods. After we had found, therefore, how well the electrical properties of steel can be thus utilized—after we had seen, for instance, that the annealing effect of temperature as low as 50° C. can be pursued and studied with the utmost nicety—the application of our method to magnetic phenomena at once forcibly presented itself. Subsequently certain analogies, which appear to exist between hardness itself when measured electrically and permanent magnetic moment, rendered the application of our method even more desirable. With regard to the second difficulty, we want in this place again to emphasize that the behavior of rods of different dimensions cannot by any means be immediately compared unless, *cæteris paribus*, the same thickness occurs throughout. Most of the observers cited, however, have obtained their results with rods for which different values of $L : D$ were secured¹²⁰ by retaining L constant and varying D . Now, it is, *a priori*, to be anticipated that glass-hardening, accompanied or not by subsequent annealing, will be productive of different effects, of states of hardness, which, even if temperature and time are identical, are structurally¹²¹ the more dissimilar in proportion as the rods subjected to these operations differ in diameter. Nor is this all. Difference of thickness usually implies a difference in chemical composition, unless, indeed, the specimens chosen are cut from the same piece of steel. To our knowledge, in none of the above researches (rods from 0.2 centimeter to 0.7 centimeter in diameter) was this done. How very different the behavior of rods frequently is, even when coming from the same source and nominally of the same kind of steel, will appear from several examples to be cited in the next paragraph.

Thomson's law, in accordance with which geometrically similar rods show equal moments per unit of mass when placed in identical magnetic fields, is probably true for iron, but cannot be immediately applied to the case of steel: possibly it may be applied to very soft rods; to a lesser extent to those in the annealed state; certainly not to glass-hard rods, inasmuch as here the peculiarities of internal structure resulting from the process of tempering manifest themselves, even in the case of

¹¹⁹ It is highly probable that a given oxide tint can be obtained in an infinite number of ways by varying temperature and time of exposure simultaneously: lower temperatures acting for very long intervals of time producing the same color effect as higher temperatures for short periods of exposure. Researches on this subject are in progress. Possibly the variation of color may correspond very closely with the actual variation of hardness, as discussed in Chapter II.

¹²⁰ All the above remarks apply to cylindrical rods of length L and diameter D .

¹²¹ Structure, as used here and elsewhere, refers to the variation of density encountered on passing along a radius from the axis of the rod to the circumference. In how far the structure of rods of different diameters will vary cannot even be conjectured.

geometrically similar figures, in a way that compels us to treat each thickness individually.¹²²

The present experiments.—The above remarks, we believe, clearly show that the whole of our knowledge on the relation of magnetism to the variables, carburization, hardness, and dimensions, is urgently in need not only of reconstruction, but of further elucidation; and we took great delight in welcoming this opportunity for the practical application of the experience which the attention of many years to the physical properties of steel has given us. The first part of our projected magnetic researches, referring principally to long, thin rods, to annealing temperatures below 500° C., and to the soft state, are herewith made public. The second part, on the behavior of short, thick rods, and on the influence of temperatures between 400° and 1,000°, will have to be reserved for another communication. We may add, more specifically, that for the 30 rods examined in the present experiments the ratio of dimensions, $\alpha = \frac{L}{D}$,

varied between $\alpha = 120$ and $\alpha = 10$. But the data in this chapter enable us to predict the magnetic behavior, even for magnets in which the said ratio (α) lies below 10 or above 120, with a degree of probability amounting almost to certainty. But, in view of the importance of thick magnets, now so largely used in magnetometric and galvanometric work, a new research on this subject seems pertinent. Similar remarks apply to high annealing temperatures.

We conclude this paragraph with the appropriate remark that our knowledge of the excessively complicated phenomena under consideration can be advanced by tentative methods alone. "The mathematical theory of the subject, even in case of homogeneous material, encounters formidable and almost insuperable difficulties. But we will be able to show in the sequel that the condition of internal structure is one of the most essential factors which determine the magnetic character of the (tempered) rod. Again, the investigation of the true nature of the structural properties of hard steel is surrounded with difficulties which will long baffle the experimentalist's skill. For in all such methods, like the one which Fromme pursued in order to obtain preliminary data on the condition of the interior of a steel rod, and in which the external layers are gradually and consecutively removed by acids or otherwise, we apprehend that the rod, for the very reason of this removal, will change its physical condition (strain) while in the hands of the operator. Long before we reach the core of the rod its density and electrical properties must be conceded to have changed materially. Nevertheless, we infer that the structure of tempered steel is of a thoroughly definite and distinct character; that this is emphatically

¹²² This inference, which we published in the same form in 1882, has since been corroborated by H. Meyer, in his paper "Ueber die Magnetisirungsfuction von Stahl u. Nickel," Wied. Ann., XVIII, p. 248, 1883. Meyer contends that Thomson's law is true neither for soft nor for hard steel rods.

demonstrated by beautiful consistency and uniformity of our different series of results, obtained with different steel rods, tempered at different times.

ON THE MATERIAL USED.

The steel.—The steel chosen was that described in the previous chapter. It was received in the shape of rods 30 centimeters long and from 0.084 centimeter to 0.150 centimeter in diameter. These were hardened as shown above (Chap. II, pp. 29–31). Analyses are superfluous, as it is our intention at present to study the results for a single value of the variable parameter, carburization, only; or, in other words, to investigate the magnetic behavior of a given type of steel. From the large supply of tempered rods such were chosen as not only showed a maximum of thermo-electric hardness for the glass-hard state, but also, when tested for longitudinal homogeneity in the manner described in pages 38, 121, gave the most satisfactory results.

Rods of like composition, thickness, temper.—At the outstart we were inclined to infer that from rods of the same kind of steel (composition), of the same thickness, and tempered in the same manner—in so far as the details of this process are at the observer's control—comparable values of the maximum of magnetic intensity could be immediately derived. For the purpose of testing this supposition, rods of nearly the same thermo-electric hardness (II, p. 65), but of different lengths, were broken from different samples of the class of rods experimented upon. These, after having been subjected alike to the action of the same magnetic field—in our case of unnecessarily great intensity and fairly uniform—according to Thomson's law ought to have retained a moment per unit of mass such as would be expressible by the same function of the ratio of length to diameter. Moreover, as the thickness of the rods chosen was practically the same, this function would have to increase to a certain limiting value, as the corresponding lengths increased from zero indefinitely.

These anticipations were, however, by no means realized. In this place it will be well to add, by way of example, such results as are particularly applicable for the illustration of the consideration just made:

A magnet 4.1 centimeters long, 0.084 centimeter thick, weighing 0.173 gram, specific resistance $s=39.8$ at 17.6 degrees, after saturation was found to have the specific magnetism $m=43.0$; whereas another specimen taken from a different rod, the magnet being only 3.05 centimeters long, 0.084 centimeter thick, weighing 0.131 gram, specific resistance $s=39.4$ at 18.5 degrees, after saturation had retained $m=52.0$; whence it appears that in the second case, notwithstanding the fact that the length (or ratio of dimensions) was only about three-fourths of that

in the first, a very decidedly greater intensity of magnetization was attainable. This is hardly referable to a difference of composition. In all probability the result is to be associated with peculiarities of the internal structure of the rods.

The following example is still more to the point:

A magnet (a) 5.0 centimeters long, 0.084 centimeter thick, weighing 0.214 gram, of the specific resistance $s=40.4$ at 18.5 degrees, had retained the specific magnetism $m=45.8$; another taken from a second rod of the same thickness, the magnet (b) being 5.9 centimeters long, as before 0.084 centimeter thick, weighing 0.249 gram, of the specific resistance $s=39.7$ at 18.3 degrees, gave, after saturation, $m=45.0$.

In order to arrive at some inference as to the cause of this difference of magnetic state, both the magnets last mentioned were slowly annealed, at first for a period of ten hours in steam, thereupon for an additional period of ten hours in aniline vapor at 185 degrees, finally for one hour in melted lead at 330 degrees. After this both were softened by heating to redness and cooling slowly. For each of the particular states of hardness thus obtained the specific resistance was measured. The rods were then magnetized to saturation and their magnetic moment determined. The results of these precursory experiments are given in the following table:

	(a)			(b)		
	<i>s</i>	<i>t</i>	<i>m</i>	<i>s</i>	<i>t</i>	<i>m</i>
Glass-hard	40.6	18	45.8	39.9	18	45.0
10 ^a in 100°	35.2	20	43.1	35.1	20	42.7
10 ^a in 185°	26.6	20	62.2	26.4	20	61.7
1 ^b in 330°	20.3	20	84.3	20.1	20	86.4
Soft	16.9	20	46.8	16.7	20	50.0

From an inspection of the table, or of Fig. 15, it is obvious that at 330° (lead bath) the magnetic intensity of the longer magnet (b) has overtaken that of (a), but it is not until both magnets are quite soft (homogeneous) that the normal behavior fully appears. It is to be noted, however, that this experiment is not in itself perfectly conclusive. The influence of carburization is principally efficient in the glass-hard state; $L:D$, if its value be as large as in the present case, less so. In the soft state, however, the effect of $L:D$ predominates. It would be possible, therefore, with due consideration of the values of s , to ascribe the results obtained to a difference of carburization between (a) and (b). The nearly equal values of specific resistance for the soft state, especially when viewed in the additional light given by the first example, make the latter inference improbable.

Each series of magnets originally integrant parts of the same hard rod.—The individuality of behavior of different rods (*i. e.*, such as are not

pieces of the same homogeneous rod, though otherwise identical) appears, therefore, to be conclusively demonstrated.¹²³

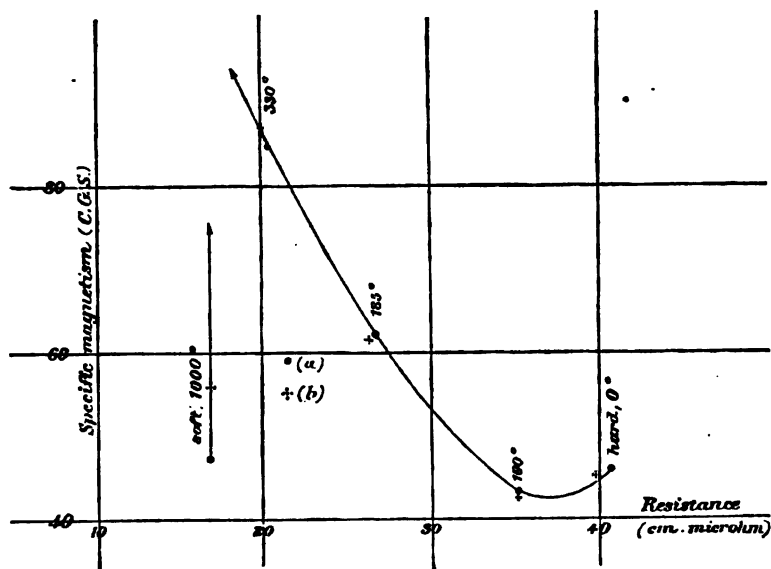


FIG. 15.—Specific magnetism of rods annealed from 0° to 1000°.

Results of this kind—a number of other examples might be cited—urged the inference upon us that only in the case where magnets are broken from one and the same longitudinally homogeneous hard rod, can comparable and harmonious results be expected. Add to this the fact that the frequent reheatings to redness, necessary in drawing a wire to small diameter, imply a difference of carburization in different samples, for this reason alone. However insignificant this may appear to be, we were convinced that its effect, where accurate results are called for, is by no means negligible. These instances are adequate to give emphasis to the statement above made, that each rod must be examined and treated separately. Indeed, a better opinion of the longitudinal homogeneity of a wire can be formed subsequently from an inspection of the behavior of the different magnets taken out of it, than could be formed at the outset by the aid of the electrical properties of different parts of the rod in question.

Unfortunately, thin (diameter = $2\rho = 0.084$ centimeter) glass-hard rods, of the same hardness throughout their length, out of which magnets of the kind desired, having different values for the ratio of dimension ($L:D$), can be broken, are only obtainable with great difficulty.

¹²³ It is quite clear that even the details of the process of tempering have an important bearing on the magnetic intensity of hard rods. A single rod repeatedly rehardened shows very marked differences in the maximum of permanent magnetization for nominally the same state.

Even those which were here finally accepted as the best for the present purposes, after the test for homogeneity was applied, proved to be satisfactory for only two-thirds of their length. The remaining third had to be discarded. There are some drawbacks in the way of heating a thin steel rod uniformly by means of the electric current. Greater difficulty is encountered in chilling it suddenly and alike throughout its length, in consequence of the large rate at which radiation takes place. Our thick rods (diameter $= 2\rho = 0.150$ centimeter) were much more uniform. The samples selected from our supply showed differences of electrical conductivity for different parts of their lengths, amounting to only a few tenths of one per cent.

METHOD OF MAGNETIZATION.

Helix. Magnetic field.—Magnetization was effected by the inductive action of a galvanic current in a helix. As a source of current the Hefner-Alteneck dynamo-electric machine of the Physical Institute of Würzburg was at our disposal. A magnetic field of very great intensity could thus easily be produced, and discrepancies due to non-saturation were therefore not to be apprehended.

The helix referred to (length $2a = 22.3$ centimeters, inner radius $r = 2.1$ centimeters, outer radius $r = 5.3$ centimeters) contained ten layers, in each of which there were $n = 55$ turns of thick copper wire.

If a current, i , circulates through the helix, the magnetizing force X_b at a point on its axis at a distance b from its center will be

$$X_b = \frac{\pi n i}{a} \left[\frac{a+b}{\sqrt{(a+b)^2 + r^2}} + \frac{a-b}{\sqrt{(a-b)^2 + r^2}} \right]$$

In our case the mean value of current was

$$i = 3.0 \frac{g^k cm^k}{sec} = 30 \text{ Amperes}$$

If this value is introduced into the formula specified and the aggregate of the value of X_b calculated, the total intensity ΣX_b of the magnetic field at different points b (cm) on the axis varied as follows:

$b =$	0	1	2	3	4	5	$\left(\frac{cm}{\frac{g^k}{cm^k sec}} \right)$
$\Sigma X_b =$	884	882	879	874	865	851	

If it be remembered that the diameter of our magnets was less than 1 millimeter, these figures show in how far the field by which magnetization was effected may be said to have been uniform. The longest magnet was 10 centimeters. In this extreme case the variation of force throughout its length amounted to less than 4 per cent. In the more

usual case of magnets of lesser length much smaller variations present themselves. On the other hand, where permanent magnetism is alone of interest and the field of great intensity, the desideratum of uniformity is perhaps of minor importance.

The mean intensity X of the magnetizing force due to a single layer of wire and corresponding to a length $2b$ (cm) symmetrically located with respect to the center of the helix is

$$X = \frac{\pi ni}{ab} \left[\sqrt{(a+b)^2 + r^2} - \sqrt{(a-b)^2 + r^2} \right]$$

In the present case the aggregate ΣX of these means, or the mean intensity of the field due to the whole helix, corresponding to the part $2b$ of the axis situated as specified was

$b =$	0	1	2	3	4	5	(cm)
$\Sigma X =$	884	893	882	880	877	874	$\frac{g^4}{cm^{\frac{1}{2}} sec}$

The largest values of ΣX employed by Ruths, for instance, in his researches on temporary magnetism, were $\Sigma X = 40$ for iron and $\Sigma X = 147$ for steel. There can be no doubt, therefore, that in our case the most complete saturation possible was actually attained. Indeed, we had frequent occasion to convince ourselves that successive magnetization produced no additional effect equivalent to one per cent. of the whole moment.

Magnetization.—In the case where magnetism is induced by means of a helix, the question in reference to the manner in which the magnets are to be introduced and withdrawn from its action is always of importance. Some observers, among them J. Wiedemann and C. Fromme, placed their magnets in the helix after the current had been closed and withdrew them before breaking it. In this way the complications due to certain undesirable induced currents are avoided. At the same time, however, the advantages of a uniform field are lost and a normal distribution of magnetism possibly interfered with. For the last mentioned reasons, Holz and Fromme preferred to open and close the current while the rod to be magnetized lay in place. Both methods have been made the subject of an experimental comparison by Fromme.¹²⁴

We gave preference to neither of these methods, but chose a plan which, under the circumstances, was also the most convenient. It consisted in allowing the current to increase from zero to its maximum value gradually and then again to wane in the same manner. This may be satisfactorily accomplished by appropriately applying the power to the dynamo-electric machine. We think we are justified in the belief that in this way the permanent magnetic moment is finally weakened only to a negligible extent, at least to a smaller amount than in either of the other methods.

¹²⁴ C. Fromme, Wied. Ann., V, p. 345, 1878.

In order to give the magnets the desired symmetrical position, relatively to the helix, a glass tube was secured coaxially with it. Into one end of this the little rods were introduced to be drawn into its center by the force of magnetic attraction. Each rod was magnetized twice, an interval of about 30 seconds¹²⁵ intervening.

MEASUREMENT OF MAGNETIC MOMENT.

Apparatus.—The magnetic moments of the wires were derived from the deflection of a small magnetized steel mirror, observed after the manner of Poggendorf with telescope and scale. We made use of an appliance due to Professor Kohlrausch, by means of which the attached magnets could always again be brought into the same position relatively to the mirror, and rotated 180° around the vertical. Both the first and the second method of Gauss were applied.

The apparatus consisted of a solid brass ring provided with leveling screws, from which two vertical columns of the same metal arose supporting a circle graduated in degrees. An alidade, with two verniers, resting on conical bearings, occupied a central position within the latter. A horizontal brass bar, in connection with the middle of the alidade, and adjustable with reference to the vertical, carried on its lower edge the special device above referred to, by the aid of which the magnets were appropriately fastened in position. This apparatus was fixed in place and adjusted at the outset, and the distance between the axis and that of the needle determined once for all. In this way the relative values of the moments of our magnets (and it is from these that the results of the present paper are principally deduced) are independent of discrepancies introduced by errors in the determination of the distance between magnet and mirror.

Method.—In calculating the results we made use of the ordinary formulæ

$$M = \frac{1}{2} \frac{r^3 T \tan \varphi}{1 + \frac{1}{2} \frac{r^3}{r^3}}$$

for the first, and

$$M = \frac{r^3 T \tan \varphi}{1 - \frac{3}{8} \frac{r^3}{r^3}}$$

for the second of the positions of Gauss, where T is the horizontal intensity of terrestrial magnetism at the place where the observations are made (in our case $T = 0.196 \frac{g^H}{cm^H \text{ sec.}}$), r the distance between magnet and needle (in our adjustment $r = 26.34$ centimeters), φ the angle of de-

¹²⁵ Frankenheim was the first to show that the number of times a magnet is exposed in a given field, and not the duration of such exposure, is of marked influence on the resultant moment (Pogg. Ann., LXXIII, p. 49, 1864).

flection, l the distance between the poles. We assumed $l=0.85 L$ where L is the length of the magnet. This approximation is sufficient because the term of the above formulæ involving l is only of the nature of a correction.

The measurements were made at ordinary temperatures, varying between 18° and 21° . The effects of the changes in the magnetic moment, as well as those due to variation of terrestrial magnetism, we regarded negligible. This is also true with reference to the torsional discrepancy of the silk fiber (the torsion-coefficient was found to be only 0.00032).

In addition to the magnetic moment M of the whole rod we shall give throughout the moment m per unit of mass (1 g.). To this quantity the name *specific magnetism* has been given. In the case where a number of different magnets are compared it is a more perspicuous result than the former.

DETERMINATION OF THE DEGREE OF HARDNESS

Resistance measurement.—Of the two methods of estimating the hardness of the rods proposed in Chapter II, one of which depends upon thermo-electric properties, the other upon the specific resistance of steel, we chose the latter because of its greater simplicity. Here again it was our object, primarily, to arrive at accurate relative values, and this we were able to accomplish satisfactorily by the aid of Matthiessen and Hockin's modification of the bridge. In one of the branches of Wheatstone's combination, the bridge cylinder of F. Kohlrausch (diagrammatically represented in Fig. 16 by the straight line AB) was inserted; in the other the steel wire D_1D_2 , whose resistance is to be measured, and a tenth Siemens unit Z_3Z_4 , the whole being appropriately connected with thick copper wire. Flat clamp-screws of brass pressed the steel rod down firmly upon a plane surface. In this way the danger of breaking the very brittle magnets was less seriously to be apprehended. The normal Z_3Z_4 was made of heavy German silver wire soldered to thick terminals. These were amalgamated and in galvanic connection with the bridge by means of mercury. From the points A and B the copper-connecting wires lead to a galvanometer, the deflections of which are observed with telescope and scale. As a source of current two Smee elements were found sufficient.

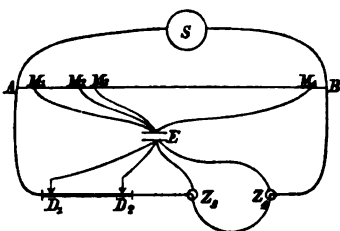


FIG. 16.—Disposition of apparatus for resistance measurement.

soldered to thick terminals. These were amalgamated and in galvanic connection with the bridge by means of mercury. From the points A and B the copper-connecting wires lead to a galvanometer, the deflections of which are observed with telescope and scale. As a source of current two Smee elements were found sufficient.

In figure 16, if the points D_1 , D_2 , Z_3 , Z_4 correspond to the points M_1 , M_2 , M_3 , M_4 , in such a way that when connected respectively with the

terminal of the battery, the current in the galvanometer (S) is zero, we have

$$\frac{D_1, D_2}{Z_3, Z_4} = \frac{M_1, M_2}{M_3, M_4}$$

To obtain the points of contact D_1 and D_2 , we made use of two steel needles, the points of which had been flattened wedge-shaped. These were fastened parallel to each other, and at a fixed distance apart, in a small piece of wood. To their tops the ends of two long thin copper wires were soldered. This arrangement, after having been screwed to a longer Γ -shaped piece of wood, along which the copper wires were led, represented as a whole a kind of tripod, two of the feet being the steel needles mentioned. During the measurements the latter stood on the steel rod to be tested. Small clamp-screws served for connecting the battery-wires with the terminals of this apparatus, these being sufficiently long and thin that the successive clamping and unclamping did not interfere with the adjustment in such a way as to slide the points D_1, D_2 along the steel rod, for instance.

This simple contrivance, which is easily improvised, gave us results of the most satisfactory kind. Our resistances were rarely larger than a few hundredths ohm. Nevertheless they were determinable with an accuracy of a few tenths per cent. with certainty. Our mirror-galvanometer enabled us to adjust the sliding contact on the bridge-cylinder of Kohlranseh to $\frac{1}{10}$ a scale-part, or $\frac{1}{10000}$ of the length of the wire A , B . In virtue of a fixed distance D_1, D_2 —we possessed a number of these arrangements to be used according as a larger or a smaller wire was to be operated upon—in view of the stability of the apparatus as a whole, and of the fact that all operations were conducted in a room of practically constant temperature, an unusual accuracy in the relative data was attained.

It is obvious that this method is applicable at once as a test for the degree of uniformity of hardness along the length of the wire. By placing the contrivance just described on different consecutive lengths without making any further alteration in the adjustments, the respective resistances of these parts could be subjected to a minute comparison. This furnishes us with the criterion desired.

Great difficulties were encountered in the measurement of the sections of the steel wires. We determined the diameter microscopically, with the aid of an ocular micrometer of known factor. Two readings, corresponding to diameters at right angles to each other, each pair taken at a number of different, approximately equidistant parts of the wires were made. The mean of these individual values was accepted. This plan was fairly good in so far as the error made in the measurement of the sections does not influence the relative values of resistance.

From the observed resistance of any wire at t degrees, the value of this quantity per meter, in ohms (w), was calculated. A knowledge of the tem

perature-coefficients of steel¹²⁶ then enabled us to deduce herefrom the specific resistance (resistance in microhms between opposite faces of a cubic centimeter) for the temperature 0°. This value, s ($\frac{\text{cm}}{\text{cm}^2}$ 0° microhm), has been adopted as a measure of hardness.

From s , the thermo-electric hardness of our wires may be calculated by the aid of the formula

$$h=0.412 s$$

In this way the present scale of hardness is made identical with that previously employed in our work on the phenomena of annealing. The data h are therefore proportional to the specific resistances of the steel rods and have a very simple connection with the respective thermo-electric constants a , as has been shown elsewhere.¹²⁷

METHOD OF ANNEALING.

Systematic plan.—In the different series of experiments the glass-hard state was chosen as the point of departure. After the rods had been examined with reference to their hardness in the way described, they were magnetized to saturation and their magnetic moment determined. Thereupon we exposed them to the annealing effect of steam at 100°. A sufficiently small decrement of hardness resulted by continuing the operation for one hour at first, and then for additional two, three, and four hours, amounting in the aggregate to ten hours of exposure. This is sufficient to bring the rod as near the limiting state, or the maximum of permanent hardness corresponding to 100° as is easily practicable.

The magnets were now subjected to the action of aniline vapor at 185°, during successive intervals of twenty minutes, forty minutes, two, four, and finally six hours.

A lead bath at 330° was next chosen. At first the magnets were annealed therein for a time of one minute only. Then the action was prolonged to one hour. In the later experiments the melting point of tin (240°) as well as that of zinc (420°) were found serviceable as temperatures of annealing.

Finally the rods were thoroughly softened in the usual way, by heating to redness and cooling very slowly. To avoid oxidation of the magnets we imbedded them in pulverized artificial ferro-ferric oxide, surrounded this with fire-clay, and finally enveloped the whole with a piece of gas-pipe.

In this way we obtained about twelve distinct states of hardness, distributed with fair uniformity between the glass hard and soft states, as

¹²⁶ Cf. Chapter I.

¹²⁷ Chapter II, p. 63.

extremes. It is only between the soft condition and that corresponding to the temperature 300° of the annealing bath that a greater number of degrees of hardness, as our results eventually showed, would have been desirable. Particularly in the case of long magnets there appear within this interval changes of magnetic capacity of a very significant character, changes, moreover, which cannot be satisfactorily supplied by a process of interpolation based on the data for neighboring states.

After the magnets had been taken out of the annealing bath it was our custom to put them aside for some time in order to allow a complete cessation of possible "after" effects. Thereupon the test for hardness was applied.

Results of the annealing.—The progress of annealing in the different experiments is fully given in the following tables:

TABLE 47.—*Thin wire.*

[2ρ=0.084 centimeter.]

Description of temper.	Specific resistance $\frac{\text{cm}}{\text{cm}^2}$ ° microhm.	
	Rod I.	Rod II.
Glass-hard	38.5	37.3
Annealed 1 hour in steam at 100°	34.8	34.7
Annealed 3 hours in steam at 100°	34.8	33.0
Annealed 6 hours in steam at 100°	33.9	32.2
Annealed 10 hours in steam at 100°	33.4	31.6
Annealed 20 minutes in aniline vapor at 185°	29.5	27.4
Annealed 1 hour in aniline vapor at 185°	28.4	26.3
Annealed 3 hours in aniline vapor at 185°	27.1	24.9
Annealed 7 hours in aniline vapor at 185°	25.9	23.7
Annealed 13 hours in aniline vapor at 185°	25.0	22.8
Annealed 1 minute in melting lead at 330°	20.4	18.9
Annealed 1 hour in melting lead at 330°	18.8	17.4
Annealed at red heat (soft)	15.7	14.5

TABLE 48.—*Thick wire.*

[2ρ=0.15 centimeter.]

Description of temper.	Specific resistance $\frac{\text{cm}}{\text{cm}^2}$ ° microhm.			
	Rod IX.	Rod X.	Rod XI.	Rod XII.
Glass-hard	47.2	46.8	43.8	42.5
Annealed 1 hour in steam at 100°	42.0	41.7	38.6	38.4
Annealed 3 hours in steam at 100°	39.5	39.3	36.5	36.2
Annealed 6 hours in steam at 100°	38.2	38.0	35.1	34.9
Annealed 10 hours in steam at 100°	37.4	37.1	34.3	34.0
Annealed 20 minutes in aniline vapor at 185°	31.5	31.4	29.0	28.7
Annealed 1 hour in aniline vapor at 185°	29.7	29.6	27.5	27.3
Annealed 3 hours in aniline vapor at 185°	27.9	27.7	25.6	25.5
Annealed 7 hours in aniline vapor at 185°	26.2	26.0	24.2	23.9
Annealed 13 hours in aniline vapor at 185°	24.8	24.6	22.9	22.7
Annealed 10 minutes in melting tin at 240°	24.0	23.8	22.2	22.0
Annealed 1 minute in melting lead at 330°	20.3	20.1	19.0	18.7
Annealed 1 hour in melting zinc at 420°	17.5	17.2	16.2	16.0
Annealed at red heat (soft)	15.7	15.6	14.9	14.9

In how far we are justified in regarding the scale of hardness for rods in the magnetized state as *cæteris paribus* identical with the scale corresponding to the unmagnetized state has been fully discussed in the previous chapter on the thermo-electric effect of magnetization.¹²²

MAGNETIC RESULTS FOR RODS OF LARGE DIMENSION-RATIO.

Description of magnets.—The results of the experiments, the plan of which has been fully detailed in the preceding paragraphs, are given in the following tables.

The first experiments were made with wire of smaller diameter. Breaking rod No. I into three parts, we obtained the magnets Nos. 1, 2, 3; and, similarly, the magnets Nos. 6, 9, 10, from rod No. II. Accidently, the longest of these, No. 10, during the course of the experiments, was further broken into parts, which, however, in their turn, were available for magnets. Nos. 5, 7, 8 were thus obtained. All magnets are numbered in the order of their respective lengths. The following table (49) contains certain important physical constants of the ten rods. We measured their dimensions first while they were in the glass-hard state; then after the various stages of annealing; finally, before and after thorough annealing at red heat. In this way we were able to arrive at numerical data for the simultaneous volume-contraction with some accuracy. Mean values are given in the tables. In calculating the specific gravity, Δ , from the mass and dimensions of the individual rods, our main object was that of checking the measurement. In view of the small diameter, Δ will not be correct within 1 per cent.

TABLE 49.—*Constants of magnets.*

Rod 2 ρ cm, Δ	Magnet No.	Mass μ	Length L	Dim. ratio a
I. 2 ρ = 0.0638 cm Δ = 7.70	1	0.086	2.00	23.9
	2	172	4.05	48.4
	3	249	5.85	69.8
	4	336	7.90	94.3
II. 2 ρ = 0.0631 cm Δ = 7.69	5	068	1.63	19.6
	6	126	3.03	36.5
	7	197	4.72	56.8
	8	236	5.66	68.1
	9	418	9.92	119.5
	10	502	12.06	145.1

The degree of homogeneity of these rods may be satisfactorily inferred from the data for s . In the case of Nos. 1, 5, 6, the method for the measurement of resistance could not readily be applied, the rods being too short. We, therefore, preferred to accept in place of such direct

¹²² Wied. Ann., XIV, p. 54, 1881. Cf. W. Beetz, Pogg. Ann., CXXVIII, p. 193, 1866.

results, the values deducible by interpolation from those obtained from rods of like origin. Data of this kind are, however, distinguished in the next table by an asterisk (*) preceding the numbers.

Magnetic data.—The magnetic measurements were made in the second position of Gauss. The numerical values of the constants occurring in the formulæ—

$$m = \frac{M}{\mu} \quad M = \frac{r^3 T \tan \varphi}{1 - \frac{r^3}{R^3}} \quad 2 \tan 2\varphi = \frac{\pi}{R}$$

are as follows:

$$T = 0.196 \frac{\text{cm}^3}{\text{sec}}$$

$$r = 26.34 \text{ cm}$$

$$R = 207.4 \text{ cm}$$

The results of the magnetic measurements are these:

TABLE 50.—*Relation between the magnetic constants of steel and hardness.*

1. *Magnets in the glass-hard state.*

Rod.	Magnet No.	α	W 1 m	t	$\frac{s}{\text{cm}^2} \text{ } ^\circ\text{C}$	n	M	m
			ohm.	°C.	microhm.	cm.	abs. E.	abs. E.
I...	1	24	*0.726	*18.2	*38.5	1.34	2.89	33.7
	2	48	0.734	17.6	38.8	3.46	7.41	43.0
	3	70	0.737	18.3	38.6	5.28	11.20	45.0
	4	94	0.716	18.7	38.1	7.68	16.06	47.9
II...	6	36	*0.719	*18.5	*37.8	2.58	5.54	43.9
	9	120	0.723	18.5	37.5	10.77	22.11	53.5
	10	145	0.714	18.5	37.1	13.78	27.65	55.1

2. *Magnets annealed 1 hour in steam.*

I...	1	24	*0.687	*18.4	*36.3	1.33	2.85	33.3
	2	48	0.695	18.2	36.7	3.38	7.23	42.0
	3	70	0.688	18.4	36.4	5.19	11.01	44.3
	4	94	0.679	18.6	35.9	7.51	15.70	46.8
II...	6	36	*0.670	*18.6	*34.7	2.53	5.44	43.1
	9	120	0.673	18.6	34.8	10.61	21.78	52.8
	10	145	0.667	18.6	34.6	13.53	27.15	54.1

3. *Magnets annealed 3 hours in steam.*

I...	1	24	*0.662	*20.1	*34.8	1.30	2.80	32.7
	2	48	0.669	20.0	35.1	3.30	7.06	41.0
	3	70	0.665	20.2	34.9	5.08	10.78	43.3
	4	94	0.653	20.2	34.4	7.41	15.49	46.2
II...	6	36	*0.641	*20.1	*33.0	2.50	5.36	42.5
	9	120	0.644	20.2	33.2	10.41	21.38	51.8
	10	145	0.638	20.1	32.9	13.29	26.67	53.2

4. *Magnets annealed 6 hours in steam.*

I...	1	24	*0.648	*21.1	*33.9	1.28	2.76	32.2
	2	48	0.654	20.9	34.2	3.23	6.91	40.1
	3	70	0.651	21.3	34.1	5.00	10.60	42.7
	4	94	0.638	21.2	33.5	7.29	15.24	45.4
II...	6	36	*0.626	*21.0	*32.2	2.47	5.31	42.0
	9	120	0.630	21.0	32.3	10.22	20.98	50.8
	10	145	0.623	21.0	32.1	13.05	26.19	52.2

TABLE 50.—*Relations between the magnetic constants of steel and hardness—Continued.*5. *Magnets annealed 10 hours in steam.*

Rod.	Magnet No.	a	W 1 m	t	$\frac{cm}{cm^3} 0^\circ$	n	M	m
			ohm.	°C.	microhm.	cm.	abs. E.	abs. E.
I....	1	24	*0.637	*20.1	*33.4	1.28	2.75	32.1
	2	48	0.645	20.2	33.7	3.24	6.93	40.2
	3	70	0.640	20.1	33.6	5.00	10.00	42.7
	4	94	0.627	20.0	33.0	7.30	15.25	45.4
II....	5	20	*0.614	*20.1	*31.6	0.93	2.01	29.6
	6	36	*0.614	*20.1	*31.6	2.42	5.19	41.1
	7	57	0.614	20.2	31.6	4.23	9.13	46.4
	8	68	0.612	20.3	31.4	5.30	11.29	47.8
	9	120	0.617	19.8	31.7	10.26	21.06	51.0

6. *Magnets annealed 20 minutes in aniline vapor.*

I....	1	24	*0.566	*20.1	*29.5	1.28	2.76	32.2
	2	48	0.572	20.1	29.7	3.45	7.98	42.8
	3	70	0.568	20.1	29.6	5.38	11.41	45.9
	4	94	0.559	20.1	29.2	7.85	16.41	48.9
II....	5	20	*0.536	*20.0	*27.4	0.92	1.98	29.1
	6	36	*0.536	*20.0	*27.4	2.56	5.51	43.6
	7	57	0.534	20.0	27.3	4.51	9.92	48.9
	8	68	0.536	20.0	27.4	5.69	12.12	51.3
	9	120	0.539	20.0	27.5	11.05	22.69	55.0

7. *Magnets annealed 1 hour in aniline vapor.*

I....	1	24	*0.545	*18.9	*28.4	1.36	2.93	34.1
	2	48	0.550	19.0	28.7	3.63	7.77	45.1
	3	70	0.546	19.0	28.5	5.64	11.96	48.1
	4	94	0.538	18.8	28.1	8.27	17.29	51.5
II....	5	20	*0.514	*18.8	*26.3	0.94	2.04	30.0
	6	36	*0.514	*18.8	*26.3	2.48	5.75	45.6
	7	57	0.515	19.0	26.4	4.75	10.14	51.5
	8	68	0.512	19.0	26.2	5.96	12.69	53.7
	9	120	0.514	18.5	26.3	11.66	23.94	58.0

8. *Magnets annealed 3 hours in aniline vapor.*

I....	1	24	*0.520	*18.9	*27.1	1.44	3.09	36.1
	2	48	0.523	18.8	27.2	3.93	8.41	48.8
	3	70	0.523	18.9	27.3	6.17	13.68	52.6
	4	94	0.514	18.0	26.8	8.99	18.80	55.0
II....	5	20	*0.488	*18.8	*24.9	1.00	2.16	31.8
	6	36	*0.488	*18.8	*24.9	2.90	6.23	49.3
	7	57	0.487	18.7	24.9	5.16	11.01	55.9
	8	68	0.486	18.8	24.8	6.46	13.76	58.2
	9	120	0.490	18.0	24.9	12.68	26.03	63.1

9. *Magnets annealed 7 hours in aniline vapor.*

I....	1	24	*0.500	*20.0	*25.9	1.51	3.25	37.9
	2	48	0.503	20.0	26.1	4.29	9.19	53.3
	3	70	0.502	20.0	26.0	6.72	14.26	57.3
	4	94	0.495	20.0	25.7	9.59	20.67	61.6
II....	5	20	*0.466	*20.0	*23.7	1.09	2.38	34.7
	6	36	*0.466	*20.0	*23.7	3.11	6.69	53.0
	7	57	0.465	20.0	23.6	5.63	12.02	61.0
	8	68	0.467	20.0	23.7	7.11	15.14	64.0
	9	120	0.467	20.0	23.7	13.88	28.50	69.0

TABLE 50.—*Relations between the magnetic constants of steel and hardness—Continued.*10. *Magnets annealed 13 hours in aniline vapor.*

Rod.	Magnet No.	a	W 1 m	t	s cm ² 0°	n	M	m
			ohm.	° C.	microhm.	cm.	abs. F.	abs. F.
I....	1	24	*0.483	*19.9	*25.0	1.50	3.42	32.9
	2	48	0.483	19.9	24.9	4.60	9.85	57.1
	3	70	0.485	19.9	25.1	7.19	15.23	61.3
	4	94	0.480	19.9	24.9	10.50	21.95	63.4
II....	5	20	*0.449	*19.9	*22.8	1.11	2.39	35.2
	6	36	*0.449	*19.9	*22.8	3.30	7.09	54.2
	7	57	0.445	19.8	22.6	6.01	12.83	65.1
	8	68	0.449	19.0	22.7	7.66	16.31	66.1
	9	120	0.454	20.0	23.0	14.69	30.16	73.1

11. *Magnets annealed 1 minute in melting lead.*

I....	1	24	*0.397	*18.6	*20.4	1.57	3.38	39.4
	2	48	0.399	18.4	20.5	5.68	12.16	70.5
	3	70	0.397	18.7	20.4	9.44	20.02	80.5
	4	94	0.394	18.7	20.3	14.06	29.40	87.6
II....	5	20	*0.374	*18.5	*18.9	0.99	2.15	31.5
	6	36	*0.374	*18.5	*18.9	3.58	7.68	56.9
	7	57	0.374	18.5	18.9	7.25	15.47	73.5
	8	68	0.373	18.7	18.8	9.32	19.85	84.0
	9	120	0.375	18.4	18.9	18.91	38.82	94.0

12. *Magnets annealed 1 hour in melting lead.*

I....	1	24	*0.367	*18.8	*18.8	1.45	3.11	38.3
	2	48	0.370	18.8	18.9	5.96	12.76	74.0
	3	70	0.367	18.8	18.8	10.18	21.48	86.4
	4	94	0.365	18.7	18.7	15.27	31.93	95.2
II....	5	20	*0.346	*18.8	*17.4	0.94	2.03	29.6
	6	36	*0.346	*18.8	*17.4	3.59	7.71	61.1
	7	57	0.345	18.8	17.4	7.62	16.25	82.5
	8	68	0.345	18.8	17.3	9.96	21.22	88.8
	9	120	0.348	18.7	17.5	20.62	42.34	102.6

13. *Magnets annealed at red heat (soft).*

I....	1	24	*0.302	*15.1	*15.7	0.32	0.69	8.0
	2	48	0.310	18.2	15.7	2.57	5.70	31.9
	3	70	0.308	18.2	15.7	6.21	13.18	53.6
	4	94	0.299	9.0	15.6	10.85	22.68	67.6
II....	5	20	*0.288	*15.4	*14.6	0.31	0.25	3.7
	6	36	*0.288	*15.4	*14.6	1.39	2.99	22.7
	7	57	0.292	18.3	14.0	4.23	9.00	45.7
	8	68	0.292	18.3	14.0	6.07	12.96	54.7
	9	120	0.279	9.6	14.5	16.23	33.55	80.7

RESULTS WITH RODS OF SMALLER DIMENSIONAL RATIO.

Description of magnets.—The rods used in the present experiments differ from the others principally in two respects: in the first place, the maximum of attainable hardness is here of much larger value than in (720)

the earlier work; in the second, the degree of longitudinal homogeneity in the glass-hard state (and we may accept this as a fair evidence of structural uniformity throughout the chosen lengths) far surpasses that hitherto obtained. Hardness was carried even as far as $s = 47.5 \left(\frac{\text{cm}}{\text{cm}^2} 0^\circ \text{ microhm} \right)^{129}$. In consequence of the exceptional homogeneity mentioned, we find that the magnetic data are in excellent accordance.

With the object of arriving at corroborative results, two pairs of wires of approximately identical degrees of galvanic hardness were selected. These are numbered IX, X, and XI, XII.¹³⁰ Each of these was broken into magnets such that the dimension-ratios $\alpha = 10, 20, 30, 40, 50$, obtained.¹³¹ Certain important physical constants of these 20 magnets, Nos. 21 to 40, have for convenience of reference here been tabulated. The remarks which precede Table 49 apply to Table 51.

TABLE 51.—*Constants of magnets.*

Rod 2ρ cm, Δ	Magnet No.	Mass μ	Length L	Dim. ratio α
IX { $2\rho=0.147$ } { $\Delta=7.46$ }	21	<i>g</i> 0.184	<i>cm.</i> 1.45	9.9
	22	0.272	2.94	20.0
	23	0.570	4.50	30.6
	24	0.764	6.14	41.1
	25	0.938	7.52	51.2
X { $2\rho=0.149$ } { $\Delta=7.58$ }	26	0.194	1.46	9.8
	27	0.386	2.92	19.6
	28	0.593	4.49	30.1
	29	0.789	5.99	40.2
	30	0.998	7.56	50.7
XI { $2\rho=0.148$ } { $\Delta=7.70$ }	31	0.194	1.47	9.6
	32	0.401	3.01	20.2
	33	0.578	4.33	29.2
	34	0.799	6.00	40.5
	35	0.979	7.38	49.8
XII { $2\rho=0.151$ } { $\Delta=7.65$ }	36	0.208	1.51	10.0
	37	0.418	3.08	20.1
	38	0.634	4.62	30.6
	39	0.827	6.04	40.0
	40	1.040	7.58	50.2

Homogeneity.—The criterion for homogeneity was applied in the manner described in p. 121 by carefully examining the rod under experiment with reference to the electrical resistance of the parts between six equidistant points, about 5 centimeters apart. We believe it expedient to

¹²⁹ The maximum hardness observed with the older material was $s=0.48$ Siemens units at 18° , therefore about $s=44.5 \left(\frac{\text{cm}}{\text{cm}^2} 0^\circ \text{ microhm} \right)$. Cf. Wied. Ann., xi, p. 945, 1880.

¹²⁰ The rods III to IX and the magnets Nos. 11 to 20 are discussed in the following chapter.

¹³¹ Of course this can only be done approximately. It is not easy to break a glass-hard rod accurately at a given point.

take the present opportunity of communicating some of these results by way of example. Table 52 contains (columns 2 to 5) the readings immediately taken from a Kohlrausch bridge. The measuring wire of this had been previously calibrated, with due allowance for the small corrections thus resulting. Column 1 shows which of the consecutive lengths (5.07 centimeters) of the steel rod corresponds to the given bridge reading, and the portion of the bridge-wire equivalent to 0.1 Siemens unit. Herefrom the absolute resistances (ohms) of the steel rods per 5.07 centimeters at t° are calculated, and the values given in columns 6 to 9. In view of these very satisfactory results, we were justified in simplifying the subsequent work by testing the homogeneity of the four longest magnets only.

TABLE 52.—*Results for homogeneity.*

	Bridge reading; scale parts.				Resistance per length 5.07 cm. (ohm).			
	IX.	X.	XI.	XII.	IX.	X.	XI.	XII.
.....					0.017	0.013	0.013	0.012
1	70.1	69.0	67.2	66.1	0.026	0.085	0.011	0.054
2	70.4	68.9	67.1	66.1	0.083	0.083	0.009	0.054
3	70.6	69.0	67.2	66.2	0.087	0.085	0.011	0.056
4	70.8	68.9	67.5	66.3	0.040	0.083	0.016	0.058
5	70.7	69.0	67.5	66.3	0.039	0.085	0.016	0.058
0.1 S. U.	468.1	474.3	488.3	502.0	.....	.....	.....	.....
$t=$	10.8	10.8	11.0	11.0	10.8	10.8	11.0	11.0

Magnetic data.—In making the magnetic measurements we used the first position of Gauss. The numerical values of the constants occurring in the formulæ

$$m = \frac{M}{\mu} \qquad M = \frac{1}{2} \frac{r^3 T \operatorname{tg} \varphi}{1 + \frac{1}{2} \frac{r^3}{R^3}} \qquad 2 \operatorname{tg} 2 \varphi = \frac{n}{R}$$

are as follows:

$$T = 0.194 \frac{\text{g}^{\frac{1}{2}}}{\text{cm}^{\frac{1}{2}} \text{ sec.}}$$

$$r = 24.90 \text{ cm.}$$

$$R = 232.8 \text{ cm.}$$

The magnetic results of our experiments, finally, are given in the series forming table (53):

TABLE 53.—*Relation between the magnetic constants of steel and hardness.*1. *Magnets in the glass-hard state.*

Rod.	Magnet No.	a	W 1 m	t	$\frac{\text{cm}}{\text{cm}^3 \text{ } ^{\circ}\text{C}}$	n	M	m
			ohm.	°C.	microhm.	cm.	abs. E.	abs. E.
IX..	21	9.9	0.283	10.8	47.2	2.60	4.17	22.7
	22	20.0	0.283	10.8	47.2	8.82	13.81	35.8
	23	30.6	0.283	10.8	47.2	14.86	23.62	41.4
	24	41.1	0.283	10.8	47.2	21.37	33.64	44.0
	25	51.2	0.283	10.8	47.2	28.18	43.86	46.0

TABLE 53.—Relation between the magnetic constants of steel and hardness—Continued.

1. Magnets in the glass-hard state—Continued.

Rod.	Magnet No.	a	W l m	t	$\frac{cm}{cm^2}$	n	M	m
			ohm.	°C.	microhm.	cm.	abs. F.	abs. F.
I.	26	9.8	0.273	11.3	48.8	2.82	4.53	23.8
	27	19.6	0.273	11.3	48.8	8.86	14.31	36.6
	28	30.1	0.273	11.3	48.8	15.83	25.14	42.4
	29	40.2	0.273	11.3	48.8	23.45	33.96	44.8
	30	50.7	0.273	11.3	48.8	29.75	44.30	46.4
II.	31	9.9	0.250	11.0	48.8	2.90	4.80	24.8
	32	20.3	0.250	11.0	48.8	10.27	18.43	41.0
	33	30.3	0.250	11.0	48.8	17.16	27.80	47.2
	34	40.5	0.250	11.0	48.8	25.77	40.50	50.8
	35	49.8	0.250	11.0	48.8	32.96	51.40	52.5
III.	36	10.0	0.248	11.0	48.5	2.96	4.79	23.0
	37	30.1	0.248	11.0	48.5	8.53	15.24	36.0
	38	30.6	0.248	11.0	48.5	17.83	27.50	43.4
	39	40.0	0.248	11.0	48.5	24.38	33.80	46.3
	40	50.2	0.248	11.0	48.5	32.26	50.22	48.3

2. Magnets annealed 1 hour in steam.

21	9.9	0.253	11.8	42.0	2.43	3.90	21.2
22	20.0	0.253	11.8	42.0	7.80	12.48	33.6
23	30.6	0.250	11.8	42.0	13.02	22.12	38.8
24	41.1	0.253	11.8	42.0	20.05	31.56	41.8
25	51.2	0.253	11.8	42.0	26.47	41.21	43.2
26	9.8	0.244	12.0	41.7	2.66	4.27	22.0
27	19.6	0.244	12.0	41.7	8.30	13.28	34.4
28	30.1	0.244	12.0	41.7	14.88	23.65	39.9
29	40.2	0.244	12.0	41.7	21.08	33.20	42.1
30	50.7	0.244	12.0	41.7	27.95	43.50	46.1
31	9.9	0.229	12.0	38.6	2.82	4.53	23.3
32	20.3	0.229	12.0	38.6	9.83	15.73	39.2
33	29.2	0.220	12.0	38.6	16.42	26.12	45.2
34	40.5	0.229	12.0	38.6	24.69	38.89	48.7
35	49.8	0.220	12.0	38.6	31.63	48.29	50.4
36	10.0	0.219	12.0	38.4	2.86	4.59	22.1
37	20.1	0.219	12.0	38.4	9.20	14.72	35.6
38	30.6	0.219	12.0	38.4	16.70	26.53	41.8
39	40.0	0.219	12.0	38.4	23.43	36.89	44.6
40	50.2	0.219	12.0	38.4	31.15	48.47	48.6

3. Magnets annealed 3 hours in steam.

21	9.9	0.238	11.9	39.5	2.46	3.94	21.4
22	20.0	0.238	11.9	39.5	7.72	12.34	33.2
23	30.6	0.238	11.9	39.5	13.09	21.76	38.2
24	41.1	0.238	11.9	39.5	19.72	31.05	40.6
25	51.2	0.238	11.9	39.5	26.89	40.30	42.3
26	9.8	0.230	11.8	38.3	2.70	4.34	22.4
27	19.6	0.230	11.8	38.3	8.21	13.13	34.0
28	30.1	0.230	11.8	38.3	14.62	23.23	39.2
29	40.2	0.230	11.8	38.3	20.05	32.53	41.2
30	50.7	0.230	11.8	38.3	27.34	42.55	42.6
31	9.9	0.216	12.0	36.5	2.88	4.54	23.4
32	20.3	0.216	12.0	36.5	9.66	15.49	33.6
33	29.2	0.216	12.0	36.5	16.16	25.70	44.5
34	40.5	0.216	12.0	36.5	24.21	38.13	47.7
35	49.8	0.216	12.0	36.5	30.94	48.22	49.3
36	10.0	0.207	12.0	36.2	2.88	4.63	22.2
37	20.1	0.207	12.0	36.2	9.12	14.59	35.3
38	30.6	0.207	12.0	36.2	16.50	26.21	41.8
39	40.0	0.207	12.0	36.2	23.09	36.85	43.9
40	50.2	0.207	12.0	36.2	30.57	47.57	45.7

TABLE 53.—*Relation between the magnetic constants of steel and hardness—Continued.*

4. Magnets annealed 6 hours in steam.

Rod.	Magnet No.	α	W/m	t	$\frac{cm}{cm^2}$	n	M	m
			dyn.	°C	mic rohm.	cm.	abs. E.	abs. E.
IX..	21	9.9	0.230	11.9	88.2	2.43	8.98	21.6
	22	20.0	0.230	11.9	88.2	7.73	12.35	23.2
	23	30.6	0.230	11.9	88.2	18.70	21.77	28.2
	24	41.1	0.230	11.9	88.2	19.63	30.90	40.4
	25	51.2	0.230	11.9	88.2	25.83	40.16	42.1
X..	26	9.8	0.223	11.9	88.0	2.70	4.34	22.4
	27	19.6	0.223	11.9	88.0	8.21	13.13	34.0
	28	30.1	0.223	11.9	88.0	14.53	22.09	38.9
	29	40.2	0.223	11.9	88.0	20.55	32.37	41.0
	30	50.7	0.223	11.9	88.0	27.24	42.89	42.5
XI..	31	9.9	0.209	11.8	85.1	2.82	4.53	23.3
	32	20.3	0.209	11.8	85.1	9.68	15.49	38.6
	33	29.2	0.209	11.8	85.1	16.09	25.60	44.3
	34	40.5	0.209	11.8	85.1	24.05	37.88	47.4
	35	49.8	0.209	11.8	85.1	30.32	48.03	49.1
XII..	36	10.0	0.199	11.8	84.9	2.84	4.56	21.9
	37	20.1	0.199	11.8	84.9	9.12	14.59	35.3
	38	30.6	0.199	11.8	84.9	16.39	26.03	41.1
	39	40.0	0.199	11.8	84.9	22.92	36.08	43.6
	40	50.2	0.199	11.8	84.9	30.41	47.32	45.5

5. Magnets annealed 10 hours in steam.

IX..	21	9.9	0.236	11.8	87.4	2.46	8.95	21.5
	22	20.0	0.236	11.8	87.4	7.73	12.37	23.3
	23	30.6	0.236	11.8	87.4	18.69	21.76	28.2
	24	41.1	0.236	11.8	87.4	19.66	30.95	40.5
	25	51.2	0.236	11.8	87.4	25.83	40.21	42.2
X..	26	9.8	0.218	11.9	87.1	2.70	4.34	22.4
	27	19.6	0.218	11.9	87.1	8.19	13.10	33.9
	28	30.1	0.218	11.9	87.1	14.57	22.16	39.0
	29	40.2	0.218	11.9	87.1	20.60	32.45	41.1
	30	50.7	0.218	11.9	87.1	27.25	42.41	42.5
XI..	31	9.9	0.204	11.9	84.8	2.81	4.51	23.3
	32	20.3	0.204	11.9	84.8	9.61	15.37	38.3
	33	29.2	0.204	11.9	84.8	16.06	25.54	44.2
	34	40.5	0.204	11.9	84.8	24.03	37.85	47.4
	35	49.8	0.204	11.9	84.8	30.74	47.91	48.9
XII..	36	10.0	0.195	11.9	84.0	2.87	4.61	22.2
	37	20.1	0.195	11.9	84.0	9.09	14.64	35.2
	38	30.6	0.195	11.9	84.0	16.34	25.95	40.9
	39	40.0	0.195	11.9	84.0	22.87	36.01	43.5
	40	50.2	0.195	11.9	84.0	30.37	47.25	45.4

6. Magnets annealed 20 minutes in aniline vapor.

IX..	21	9.9	0.191	12.0	81.5	2.81	3.71	20.2
	22	20.0	0.191	12.0	81.5	7.97	12.75	34.3
	23	30.6	0.191	12.0	81.5	14.60	23.21	40.7
	24	41.1	0.191	12.0	81.5	21.15	33.30	43.6
	25	51.2	0.191	12.0	81.5	28.02	43.62	45.8
X..	26	9.8	0.185	12.0	81.4	2.60	4.18	21.5
	27	19.6	0.185	12.0	81.4	8.45	13.32	35.0
	28	30.1	0.185	12.0	81.4	15.48	24.60	41.5
	29	40.2	0.185	12.0	81.4	22.22	34.90	44.4
	30	50.7	0.185	12.0	81.4	29.58	45.04	46.1
XI..	31	9.9	0.173	12.0	29.0	2.54	4.08	21.0
	32	20.3	0.173	12.0	29.0	9.75	15.60	38.9
	33	29.2	0.173	12.0	29.0	16.70	26.56	44.0
	34	40.5	0.173	12.0	29.0	25.52	40.20	50.3
	35	49.8	0.173	12.0	29.0	32.87	51.23	52.3
XII..	36	10.0	0.165	12.0	28.7	2.67	4.29	20.6
	37	20.1	0.165	12.0	28.7	8.28	14.94	35.9
	38	30.6	0.165	12.0	28.7	17.81	27.49	43.7
	39	40.0	0.165	12.0	28.7	24.52	38.00	46.0
	40	50.2	0.165	12.0	28.7	32.75	50.96	49.4

TABLE 53.—Relation between the magnetic constants of steel and hardness—Continued.

7. Magnets annealed 1 hour in aniline vapor.

Rod.	Magnet No.	σ	Wlm	t	$\frac{cm}{cm^2}$	n	M	m
			cm.	°C.	microhm.	cm.	abs. E.	abs. E.
IX..	21	9.9	0.179	12.0	29.7	2.88	3.75	20.4
	22	20.0	0.179	12.0	29.7	8.80	12.28	35.7
	23	39.6	0.179	12.0	29.7	15.38	24.45	42.9
	24	41.1	0.179	12.0	29.7	22.87	35.22	46.1
	25	51.2	0.179	12.0	29.7	29.75	46.31	48.6
X..	26	9.8	0.175	12.0	29.6	2.52	4.05	20.9
	27	19.6	0.175	12.0	29.6	8.79	14.06	38.4
	28	30.1	0.175	12.0	29.6	16.31	25.92	43.7
	29	40.2	0.175	12.0	29.6	23.60	37.17	47.1
	30	50.7	0.175	12.0	29.6	31.46	48.97	49.1
XI..	31	9.9	0.164	12.0	27.5	2.57	4.13	21.3
	32	20.3	0.164	12.0	27.5	10.08	16.13	40.2
	33	39.2	0.164	12.0	27.5	17.49	27.82	48.1
	34	40.5	0.164	12.0	27.5	26.83	42.26	52.9
	35	49.8	0.164	12.0	27.5	34.64	53.99	55.1
XII..	36	10.0	0.157	12.0	27.3	2.06	4.27	20.5
	37	20.1	0.157	12.0	27.3	9.00	15.36	37.2
	38	30.6	0.157	12.0	27.3	18.19	28.89	45.6
	39	40.0	0.157	12.0	27.3	25.88	40.75	49.3
	40	50.2	0.157	12.0	27.3	34.63	53.89	51.8

8. Magnets annealed 3 hours in aniline vapor.

IX..	21	9.9	0.169	11.7	27.9	2.41	3.87	21.0
	22	20.0	0.169	11.7	27.9	8.99	14.88	38.7
	23	39.6	0.169	11.7	27.9	16.98	26.91	47.2
	24	41.1	0.169	11.7	27.9	24.75	38.97	51.0
	25	51.2	0.169	11.7	27.9	32.94	51.27	53.8
X..	26	9.8	0.164	11.8	27.7	2.62	4.21	21.7
	27	19.6	0.164	11.8	27.7	9.56	15.30	39.6
	28	30.1	0.164	11.8	27.7	18.08	28.73	48.5
	29	40.2	0.164	11.8	27.7	26.23	41.31	52.4
	30	50.7	0.164	11.8	27.7	35.06	54.56	54.7
XI..	31	9.9	0.153	11.8	25.6	2.61	4.19	21.6
	32	20.3	0.153	11.8	25.6	10.71	17.13	42.7
	33	39.2	0.153	11.8	25.6	18.98	30.19	52.2
	34	40.5	0.153	11.8	25.6	29.25	46.07	57.7
	35	49.8	0.153	11.8	25.6	37.83	58.95	60.2
XII..	36	10.0	0.147	11.9	25.5	2.75	4.42	21.2
	37	20.1	0.147	11.9	25.5	10.29	16.46	39.8
	38	30.6	0.147	11.9	25.5	19.81	31.46	49.6
	39	40.0	0.147	11.9	25.5	28.87	44.67	54.0
	40	50.2	0.147	11.9	25.5	38.16	59.37	57.1

9. Magnets annealed 7 hours in aniline vapor.

IX..	21	9.9	0.159	12.0	26.2	2.53	4.06	22.1
	22	20.0	0.159	12.0	26.2	9.80	15.68	42.2
	23	39.6	0.159	12.0	26.2	18.73	28.76	52.2
	24	41.1	0.159	12.0	26.2	27.65	48.53	57.0
	25	51.2	0.159	12.0	26.2	37.03	57.65	60.5
X..	26	9.8	0.154	12.0	26.0	2.68	4.30	22.2
	27	19.6	0.154	12.0	26.0	10.86	16.58	42.9
	28	30.1	0.154	12.0	26.0	20.06	31.88	53.8
	29	40.2	0.154	12.0	26.0	29.31	46.16	58.5
	30	50.7	0.154	12.0	26.0	39.39	61.31	61.4
XI..	31	9.9	0.145	12.0	24.2	2.63	4.23	21.8
	32	20.3	0.145	12.0	24.2	11.40	18.24	45.5
	33	39.2	0.145	12.0	24.2	20.69	32.92	56.9
	34	40.5	0.145	12.0	24.2	32.19	50.70	68.5
	35	49.8	0.145	12.0	24.2	41.96	65.39	66.8
XII..	36	10.0	0.138	12.0	23.9	2.80	4.50	21.6
	37	20.1	0.138	12.0	23.9	11.01	17.61	42.6
	38	30.6	0.138	12.0	23.9	21.78	34.51	54.4
	39	40.0	0.138	12.0	23.9	31.82	49.91	59.6
	40	50.2	0.138	12.0	23.9	42.87	65.96	63.4

TABLE 53.—*Relation between the magnetic constants of steel and hardness—Continued.*10. *Magnets annealed 18 hours in aniline vapor.*

Rod.	Magnet No.	α	$W \text{ in}$	t	$\frac{e \text{ cm}}{s \text{ cm}^2} \text{ } ^\circ\text{C}$	n	M	m
			ohm.	°C.	microhm.	cm.	abs. E.	abs. E.
IX..	21	9.9	0.151	12.0	24.8	2.50	4.02	21.8
	22	20.0	0.151	12.0	24.8	10.25	16.40	44.1
	23	30.6	0.151	12.0	24.8	20.09	31.93	56.0
	24	41.1	0.151	12.0	24.8	30.02	47.26	61.9
	25	51.2	0.151	12.0	24.8	40.25	62.66	63.8
X..	26	9.8	0.146	12.0	24.6	2.64	4.24	21.9
	27	19.6	0.146	12.0	24.6	10.79	17.26	44.7
	28	30.1	0.146	12.0	24.6	21.59	34.92	57.9
	29	40.2	0.146	12.0	24.6	31.87	50.20	63.6
	30	50.7	0.146	12.0	24.6	42.96	66.87	67.0
XI..	31	9.9	0.138	12.0	22.9	2.53	4.06	20.9
	32	20.3	0.138	12.0	22.9	11.59	18.54	46.2
	33	29.2	0.138	12.0	22.9	21.68	34.49	59.7
	34	40.5	0.138	12.0	22.9	34.53	54.39	68.1
	35	49.8	0.138	12.0	22.9	45.08	70.26	71.8
XII..	36	10.0	0.132	12.0	22.7	2.73	4.38	21.1
	37	20.1	0.132	12.0	22.7	11.80	18.08	43.8
	38	30.6	0.132	12.0	22.7	22.90	36.37	57.4
	39	40.0	0.132	12.0	22.7	33.50	52.74	63.8
	40	50.2	0.132	12.0	22.7	45.60	70.96	68.2

11. *Magnets annealed 10 minutes in melting tin.*

IX..	21	9.9	0.147	11.7	24.0	2.46	3.95	21.5
	22	20.0	0.147	11.7	24.0	10.37	16.50	44.6
	23	30.6	0.147	11.7	24.0	20.64	32.80	57.5
	24	41.1	0.147	11.7	24.0	30.97	48.75	63.8
	25	51.2	0.147	11.7	24.0	41.92	65.25	68.5
X..	26	9.8	0.141	11.5	23.8	2.60	4.18	21.3
	27	19.6	0.141	11.5	23.8	10.98	17.57	45.3
	28	30.1	0.141	11.5	23.8	22.28	35.41	59.7
	29	40.2	0.141	11.5	23.8	33.11	52.16	66.1
	30	50.7	0.141	11.5	23.8	44.78	69.70	69.8
XI..	31	9.9	0.134	11.6	22.2	2.46	3.95	20.4
	32	20.3	0.134	11.6	22.2	11.70	18.72	46.7
	33	29.2	0.134	11.6	22.2	22.17	35.27	61.0
	34	40.5	0.134	11.6	22.2	35.60	56.07	70.2
	35	49.8	0.134	11.6	22.2	46.70	72.78	74.3
XII..	36	10.0	0.127	11.7	22.0	2.68	4.30	20.7
	37	20.1	0.127	11.7	22.0	11.37	18.19	44.0
	38	30.6	0.127	11.7	22.0	23.47	37.27	58.8
	39	40.0	0.127	11.7	22.0	34.58	54.44	65.8
	40	50.2	0.127	11.7	22.0	47.29	73.59	70.8

12. *Magnets annealed 1 minute in melting lead.*

IX..	21	9.9	0.124	11.9	20.3	2.26	3.60	19.7
	22	20.0	0.124	11.9	20.3	10.88	17.40	43.8
	23	30.6	0.124	11.9	20.3	24.04	38.19	67.0
	24	41.1	0.124	11.9	20.3	38.43	60.51	79.2
	25	51.2	0.124	11.9	20.3	52.53	81.77	85.8
X..	26	9.8	0.120	11.3	20.1	2.38	3.74	19.3
	27	19.6	0.120	11.3	20.1	11.14	17.63	43.2
	28	30.1	0.120	11.3	20.1	25.34	40.27	67.9
	29	40.2	0.120	11.3	20.1	40.08	63.12	80.0
	30	50.7	0.120	11.3	20.1	55.46	86.32	86.5
XI..	31	9.9	0.115	11.9	19.0	2.30	3.69	19.0
	32	20.3	0.115	11.9	19.0	11.71	18.72	46.7
	33	29.2	0.115	11.9	19.0	24.71	39.80	68.0
	34	40.5	0.115	11.9	19.0	42.45	66.87	83.7
	35	49.8	0.115	11.9	19.0	56.53	88.10	90.0
XII..	36	10.0	0.109	11.9	18.7	2.46	3.95	19.0
	37	20.1	0.109	11.9	18.7	11.18	17.89	43.8
	38	30.6	0.109	11.9	18.7	25.95	41.21	65.0
	39	40.0	0.109	11.9	18.7	41.39	65.16	78.8
	40	50.2	0.109	11.9	18.7	58.01	90.26	86.8

TABLE 53.—Relation between the magnetic constants of steel and hardness—Continued.

13. Magnets annealed 1 hour in molting zinc.

Red.	Magnet No.	a	W in	t	$\frac{S}{cm^2}^{100}$	n	M	w
			ohm.	°C.	microhm.	cm.	abs. B.	abs. B.
IX..	21	9.9	0.107	10.3	17.5	1.85	2.96	16.2
	22	20.0	0.107	10.3	17.5	10.15	16.24	43.7
	23	30.6	0.107	10.3	17.5	26.02	41.35	72.5
	24	41.1	0.107	10.3	17.5	43.90	69.12	90.5
	25	51.2	0.107	10.3	17.5	61.65	95.96	100.7
X..	26	9.8	0.103	10.3	17.2	1.83	2.94	15.2
	27	19.6	0.103	10.3	17.2	9.82	15.71	40.7
	28	30.1	0.103	10.3	17.2	26.89	42.64	72.1
	29	40.2	0.103	10.3	17.2	46.08	72.49	91.9
	30	50.7	0.103	10.3	17.2	65.10	101.32	101.5
XI..	31	9.9	0.098	10.3	16.2	1.74	2.79	14.4
	32	20.2	0.098	10.3	16.2	10.06	16.08	40.1
	33	29.2	0.098	10.3	16.2	26.87	42.74	72.6
	34	40.5	0.098	10.3	16.2	47.63	75.03	98.9
	35	49.8	0.098	10.3	16.2	65.29	101.74	108.9
XII..	36	10.0	0.098	10.3	16.0	1.98	2.10	14.9
	37	20.1	0.098	10.3	16.0	9.95	15.91	38.5
	38	30.6	0.093	10.3	16.0	27.14	43.10	68.0
	39	40.0	0.093	10.3	16.0	48.73	73.57	90.0
	40	50.2	0.093	10.3	16.0	67.69	103.17	101.1

14. Magnets annealed at red heat (soft).

IX..	21	9.9	0.098	10.0	15.7	0.53	0.83	4.5
	22	20.0	0.098	10.0	15.7	2.72	4.35	11.7
	23	30.6	0.098	10.0	15.7	7.94	12.62	22.1
	24	41.1	0.098	10.0	15.7	10.87	26.56	34.8
	25	51.2	0.098	10.0	15.7	28.49	44.35	64.5
X..	26	9.8	0.093	10.1	15.6	0.46	0.74	3.8
	27	19.6	0.093	10.1	15.6	2.52	4.03	10.5
	28	30.1	0.093	10.1	15.6	7.59	12.06	20.3
	29	40.2	0.093	10.1	15.6	15.72	24.77	31.4
	30	50.7	0.093	10.1	15.6	29.15	45.26	45.4
XI..	31	9.9	0.098	10.2	14.9	0.82	0.84	4.3
	32	20.2	0.098	10.2	14.9	2.55	4.08	10.2
	33	29.2	0.098	10.2	14.9	6.80	10.82	18.7
	34	40.5	0.098	10.2	14.9	15.13	23.83	29.8
	35	49.8	0.098	10.2	14.9	26.63	41.50	42.4
XII..	36	10.0	0.087	10.2	14.9	0.57	0.92	4.4
	37	20.1	0.087	10.2	14.9	3.15	5.04	12.2
	38	30.6	0.087	10.2	14.9	8.25	13.10	20.7
	39	40.0	0.087	10.2	14.9	16.32	25.69	31.1
	40	50.2	0.087	10.2	14.9	29.42	36.36	44.0

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DISCUSSION.

Digest.—Our present purpose will be greatly facilitated by a tabular comparison of the essential features of the results in hand. The following digest (Tables 54 to 59) contains, besides brief descriptions of temper, the hardness as represented by the specific resistance s , together with the corresponding magnetic moments per unit of mass, m , of the several rods.

TABLE 54.—Rod I.

Description of temper.	Hardness, s .	Specific magnetism, m .			
		No. 1.	No. 2.	No. 3.	No. 4.
Glass-hard	38.5	33.7	41.0	45.0	47.9
Annealed 1 hour in steam 100°	36.3	33.3	42.0	44.3	46.8
Annealed 3 hours in steam 100°	34.8	32.7	41.0	43.3	46.2
Annealed 6 hours in steam 100°	33.9	32.2	40.1	42.7	45.4
Annealed 10 hours in steam 100°	33.4	32.1	40.2	42.7	45.4
Annealed 20 minutes in aniline vapor 185°	29.5	32.2	42.8	45.9	48.9
Annealed 1 hour in aniline vapor 185°	28.4	34.1	45.1	48.1	51.5
Annealed 3 hours in aniline vapor 185°	27.1	36.1	48.8	52.6	56.0
Annealed 7 hours in aniline vapor 185°	25.9	37.9	53.3	57.3	61.6
Annealed 13 hours in aniline vapor 185°	25.0	39.9	57.1	61.3	65.4
Annealed 1 minute in lead bath 330°	20.4	39.4	70.5	80.5	87.6
Annealed 1 hour in lead bath 330°	18.8	38.3	74.0	86.4	95.2
Soft	15.7	8.0	31.9	53.0	67.6

TABLE 55.—Rod II.

Description of temper.	Hardness, s .	Specific magnetism, m .					
		No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.
Glass-hard	37.3	43.9	.....	.....	.....	53.5	55.1
Annealed 1 hour in steam 100°	34.7	43.1	.....	.....	.....	53.8	54.1
Annealed 3 hours in steam 100°	33.0	42.5	.....	.....	.....	51.8	53.2
Annealed 6 hours in steam 100°	32.2	42.0	.....	.....	.....	50.8	52.3
Annealed 10 hours in steam 100°	31.6	29.6	41.1	46.4	47.8	51.0	.....
Annealed 20 minutes in aniline vapor 185°	27.4	29.1	43.6	48.9	51.8	55.0	.....
Annealed 1 hour in aniline vapor 185°	26.3	30.0	45.6	51.5	53.7	58.0	.....
Annealed 3 hours in aniline vapor 185°	24.9	31.8	49.3	55.9	58.2	63.1	.....
Annealed 7 hours in aniline vapor 185°	23.7	34.7	53.0	61.0	64.0	69.0	.....
Annealed 13 hours in aniline vapor 185°	22.3	35.2	56.2	66.1	69.1	73.1	.....
Annealed 1 minute in lead bath 330°	18.9	31.5	60.0	78.5	84.0	94.0	.....
Annealed 1 hour in lead bath 330°	17.4	29.8	61.1	82.5	89.8	102.6	.....
Soft	14.5	8.7	23.7	45.7	54.7	80.7	.....

TABLE 56.—Rod IX.

Description of temper.	Hardness, s .	Specific magnetism m , for the dimension-ratio =				
		9.9	20.0	30.6	41.1	51.2
Glass-hard	47.2	22.7	35.8	41.4	44.0	46.0
Annealed 1 hour in steam 100°	42.0	21.2	33.6	38.8	41.3	43.2
Annealed 3 hours in steam 100°	39.5	21.4	33.2	38.2	40.6	42.3
Annealed 6 hours in steam 100°	38.2	21.6	33.2	38.2	40.4	42.1
Annealed 10 hours in steam 100°	37.4	21.5	33.8	38.2	40.5	42.2
Annealed 20 minutes in aniline vapor 185°	31.5	20.2	34.8	40.7	43.6	45.8
Annealed 1 hour in aniline vapor 185°	29.7	20.4	35.7	42.9	46.1	48.6
Annealed 3 hours in aniline vapor 185°	27.9	21.0	38.7	47.2	51.0	53.8
Annealed 7 hours in aniline vapor 185°	26.2	22.1	42.2	52.2	57.0	60.5
Annealed 13 hours in aniline vapor 185°	24.8	21.8	44.1	56.0	61.9	65.8
Annealed 10 minutes in tin bath 240°	24.0	21.5	44.6	57.5	63.8	68.5
Annealed 1 minute in lead bath 330°	20.3	19.7	46.8	57.0	79.2	85.8
Annealed 1 hour in zinc bath 450°	17.6	16.2	43.7	72.5	90.5	100.7
Soft	13.7	4.5	11.7	22.1	34.8	46.5

TABLE 57.—*Rod X.*

Description of temper.	Hardness, <i>s</i> .	Specific magnetism m , for the dimension-ratio=				
		9.8	19.6	30.1	40.2	50.7
Glass-hard.....	46.8	23.3	36.8	42.4	44.8	46.4
Annealed 1 hour in steam 100°.....	41.7	23.0	34.4	39.9	42.1	43.6
Annealed 2 hours in steam 100°.....	39.3	22.4	34.0	39.2	41.2	42.6
Annealed 6 hours in steam 100°.....	38.0	22.4	34.0	38.9	41.0	42.5
Annealed 10 hours in steam 100°.....	37.1	22.4	33.9	39.0	41.1	42.5
Annealed 20 minutes in aniline vapor 185°.....	31.4	21.5	35.0	41.5	44.4	46.1
Annealed 1 hour in aniline vapor 185°.....	29.6	20.9	36.4	43.7	47.1	49.1
Annealed 3 hours in aniline vapor 185°.....	27.7	21.7	39.6	48.5	52.4	54.7
Annealed 7 hours in aniline vapor 185°.....	26.0	22.2	42.9	53.8	58.5	61.4
Annealed 13 hours in aniline vapor 185°.....	24.6	21.9	44.7	57.9	63.6	67.0
Annealed 10 minutes in tin bath 240°.....	23.8	21.5	45.5	59.7	66.1	69.8
Annealed 1 minute in lead bath 330°.....	20.1	19.3	46.2	67.9	80.0	86.5
Annealed 1 hour in zinc bath 420°.....	17.2	15.2	46.7	72.1	91.9	101.5
Soft.....	15.6	8.8	10.5	20.8	31.4	45.4

TABLE 58.—*Rod XI.*

Description of temper.	Hardness, <i>s</i> .	Specific magnetism m , for the dimension-ratio=				
		9.9	20.3	29.2	40.5	49.8
Glass-hard.....	43.8	24.3	41.0	47.2	50.8	52.5
Annealed 1 hour in steam 100°.....	38.6	23.3	39.2	45.2	48.7	50.4
Annealed 3 hours in steam 100°.....	36.5	23.4	38.6	44.5	47.7	49.3
Annealed 6 hours in steam 100°.....	35.1	23.3	38.6	44.3	47.4	49.1
Annealed 10 hours in steam 100°.....	34.3	23.2	38.3	44.2	47.4	48.9
Annealed 20 minutes in aniline vapor 185°.....	29.0	21.0	38.9	46.0	50.3	52.3
Annealed 1 hour in aniline vapor 185°.....	27.5	21.3	40.2	48.1	52.9	55.1
Annealed 3 hours in aniline vapor 185°.....	25.6	21.6	42.7	52.2	57.7	60.3
Annealed 7 hours in aniline vapor 185°.....	24.2	21.8	45.5	56.9	63.5	66.8
Annealed 13 hours in aniline vapor 185°.....	22.9	20.9	46.2	59.7	68.1	71.8
Annealed 10 minutes in tin bath 240°.....	22.2	20.4	46.7	61.0	70.2	74.3
Annealed 1 minute in lead bath 330°.....	19.0	19.0	46.7	68.0	83.7	90.0
Annealed 1 hour in zinc bath 420°.....	16.2	14.4	40.1	72.6	93.9	103.9
Soft.....	14.9	4.3	10.2	18.7	29.8	42.4

TABLE 59.—*Rod XII.*

Description of temper.	Hardness, <i>s</i> .	Specific magnetism m , for the dimension-ratio=				
		10.0	20.1	30.6	40.0	50.2
Glass-hard.....	43.5	23.0	36.9	43.4	46.3	48.3
Annealed 1 hour in steam 100°.....	38.4	22.1	35.6	41.8	44.6	46.6
Annealed 3 hours in steam 100°.....	36.2	22.2	35.3	41.3	43.9	45.7
Annealed 6 hours in steam 100°.....	34.9	21.9	35.3	41.1	43.6	45.5
Annealed 10 hours in steam 100°.....	34.0	22.2	35.2	40.9	43.5	45.4
Annealed 20 minutes in aniline vapor 185°.....	28.7	20.6	35.9	43.4	46.7	49.0
Annealed 1 hour in aniline vapor 185°.....	27.3	20.5	37.2	45.6	49.2	51.8
Annealed 3 hours in aniline vapor 185°.....	25.5	21.2	39.8	49.6	54.0	57.1
Annealed 7 hours in aniline vapor 185°.....	23.9	21.6	42.6	54.4	59.6	63.4
Annealed 13 hours in aniline vapor 185°.....	22.7	21.1	43.8	57.4	63.8	68.2
Annealed 10 minutes in tin-bath 240°.....	22.0	20.7	44.0	58.8	65.8	70.8
Annealed 1 minute in lead-bath 330°.....	18.7	19.0	43.3	65.0	78.8	86.8
Annealed 1 hour in zinc-bath 420°.....	16.0	14.9	38.5	68.0	89.0	101.1
Soft.....	14.9	4.4	12.2	20.7	31.1	44.0

Plan of the discussion.—These results may be discussed from two distinct stand-points. In case of one and the same wire, the specific magnetism of the magnets taken out of it varies both with their degree

of hardness and with the ratio of length and diameter. In place of a diagram in three dimensions, however, it is expedient to regard the one or the other variable, as an arbitrary constant, while the other passes through all possible values. We thus represent all relations by plane diagrams. Our results are compared in this way. It is, however, convenient to replace Tables 54 and 55 by others satisfactorily deducible from them by graphic interpolation, since the ratio of dimensions in the earlier experiments (Tables 54 and 55) do not compare well with those in the later (Tables 56 to 59). In other words, without such reconstruction of the former results, the difference of magnetic behavior of the two kinds of steel employed cannot be readily discerned. For this reason the Tables 60 and 61, following, have been prepared. The data contained are such as would have been found if the ratio of dimensions had been $\alpha=20, 40, 60, 80$, and 100 , respectively, in place of the values which actually obtained.

TABLE 60.—*Rod I.*

Description of temper.	Hardness, <i>s</i> .	Specific magnetism <i>m</i> , for the dimension-ratio=				
		20	40	60	80	100
Glass-hard	88.5	31.4	40.2	44.3	46.5	48.0
Annealed 1 hour in steam 100°	36.3	30.5	38.2	42.9	44.7	46.0
Annealed 3 hours in steam 100°	34.8	30.1	38.5	42.2	43.9	45.2
Annealed 6 hours in steam 100°	33.9	29.9	38.3	42.0	43.8	45.0
Annealed 10 hours in steam 100°	33.4	29.8	38.0	41.8	43.8	45.2
Annealed 20 minutes in aniline vapor 185°	29.5	29.6	40.0	44.5	47.2	49.4
Annealed 1 hour in aniline vapor 185°	28.4	30.3	42.3	47.4	50.8	52.3
Annealed 3 hours in aniline vapor 185°	27.1	31.8	46.2	51.6	54.4	56.5
Annealed 7 hours in aniline vapor 185°	25.9	33.6	50.4	56.0	59.1	61.4
Annealed 13 hours in aniline vapor 185°	25.0	34.7	52.6	60.0	63.4	65.8
Annealed 1 minute in lead-bath 330°	20.4	32.2	63.4	77.3	84.2	89.2
Annealed 1 hour in lead-bath 330°	18.8	26.0	65.3	81.4	90.3	97.2
Soft	15.7	6.0	21.3	48.0	59.4	70.3

TABLE 61.—*Rod II.*

Description of temper.	Hardness, <i>s</i> .	Specific magnetism <i>m</i> , for the dimension-ratio=				
		20	40	60	80	100
Glass-hard	37.3	31.5	45.0	49.5	51.3	52.4
Annealed 1 hour in steam 100°	34.7	30.4	43.4	47.8	49.7	50.5
Annealed 3 hours in steam 100°	33.0	30.0	42.8	47.3	49.0	49.9
Annealed 6 hours in steam 100°	32.2	29.9	42.7	47.2	48.8	49.8
Annealed 10 hours in steam 100°	31.6	29.9	42.7	47.2	48.8	49.7
Annealed 20 minutes in aniline vapor 185°	27.4	29.4	45.3	50.1	52.5	54.0
Annealed 1 hour in aniline vapor 185°	26.3	30.0	47.3	52.2	55.0	56.6
Annealed 3 hours in aniline vapor 185°	24.9	32.3	50.9	57.3	60.0	62.2
Annealed 7 hours in aniline vapor 185°	23.7	34.3	54.7	62.3	66.0	68.0
Annealed 13 hours in aniline vapor 185°	22.8	35.0	58.0	66.4	70.8	72.0
Annealed 1 minute in lead-bath 330°	18.9	33.0	64.3	80.7	88.6	92.2
Annealed 1 hour in lead-bath 330°	17.4	30.0	65.3	84.6	95.0	100.3
Soft	14.5	6.0	27.3	47.5	63.3	74.0

General inferences.—A detailed comparison of the results expressed in Tables 60 and 61 with those in Tables 53, 57, 58, 59, and all of these among themselves, shows conclusively that the magnetic behavior of

each particular wire is of a distinct and individual character. More perspicuously, even, the same fact is observable in a graphic representation of the data. The curves obtained for the several wires are by no means coincident. The thicker wire shows greater magnetizability than the wire of smaller diameter. In the case of both kinds of steel, galvanically hard rods are magnetizable to a lesser degree than soft rods. Moreover, there appears to exist a relation between the density and maximum permanent moment, in so far as the latter in general increases directly with the former. This effect is particularly apparent for the thicker wire. But the fundamental inference is this, that the relation between specific magnetism and hardness expressed galvanically, as exhibited by all the wires, is essentially of the same kind.

Magnetism and hardness.—The general contours of the families of curves expressing the functionality between magnetic moment, per unit of mass, hardness, ratio of dimensions, are of very great interest. It appears clearly that the latter variable by no means deserves the exclusive importance which has hitherto been attributed to it, at least not in the accepted sense that a certain critical value exists (Ruths, for instance, puts it, $\alpha=35$) below which magnets differ in a pronounced way as regards magnetizability, from magnets with a larger dimension-ratio. The variations of the series of curves belonging to magnets taken from one and the same wire are obviously of like nature; in other words, obtained from a definite law by the mere change of a parametric constant, α . In general, all magnets, whether long or short, after incipient annealing diminish in magnetizability, until a well-marked minimum of this quality is reached. If thereafter annealing be continued magnetizability again increases, attains a maximum, and finally decreases again to the value for the soft state.

The causes which led earlier observers into partially erroneous inferences are not far to seek. With the ordinary very rough method of estimating the degree of hardness of steel by the aid of the oxide tints, the character of the curves, as a whole, did not appear. Hitherto data for only four points for each rod, corresponding to the hard, the yellow, the blue, and the soft states, were available. Irrespective of the vagueness of degrees of hardness thus defined it will readily be seen that where the full contours of the curves are unknown the grouping of these points is such as to suggest the said imperfect inference of a critical dimension-ratio.

The effect of a variation of dimensions is particularly apparent in its bearing on the position and value of the minima and maxima of the permanently saturated magnetic state. In proportion as the length of the magnets, or more accurately the ratio of dimensions increases, these singular points, which are nearly coincident in very short rods, move apart, the minimum occurring in the glass-hard state, the maximum passing at a very rapid rate toward the soft state. At the same time the maximum increases enormously in value, and for long, thin rods is

greater than twice the equivalent of the permanently saturated magnetic moment of the same rod when hard. As we approach short rods, as will be seen, the maximum flattens out, moving toward the minimum at a more rapid rate than the minimum progresses in the opposite direction. But the variations are such that for very short magnets, *i. e.*, such for which the ratio of dimensions is below 5, the minimum will probably lose its marked character altogether, and eventually come into full coincidence with the maximum. Here, therefore, a uniformly continuous decrease of magnetizability from the glass-hard to the soft states is to be anticipated.

Graphic representation.—All these results may be made to appear with striking clearness by representing them graphically. It will be sufficient for this purpose to accept the mean of the two series of results for the thin sample of steel wire, and then to compare this with the mean or combined results (four series) obtaining for the thicker sample of wire. These mean values are given in the following tables, 62 and 63:

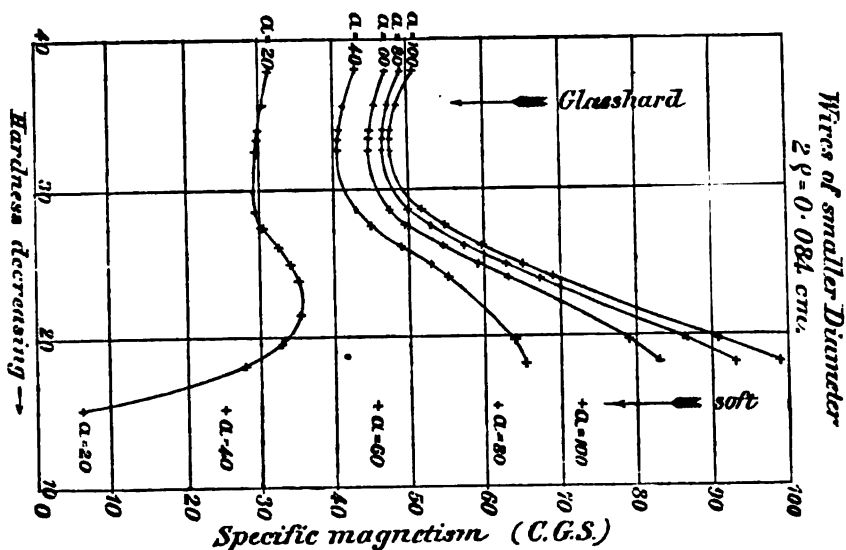
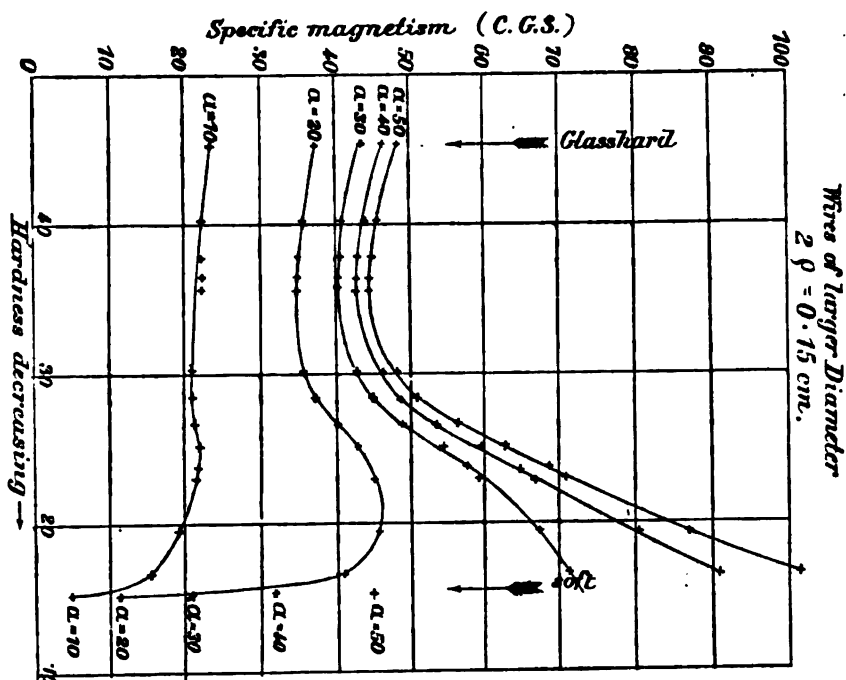
TABLE 62.—*Progressive states of magnetisability, varying with hardness.*[Thick wire, $2\rho=0.15$ centimeter.]

Mean hardness (galvan).	Mean specific magnetism m , for the dimension-ratio =				
	10	20	30	40	50
45.3	23.5	37.6	43.6	46.5	48.8
40.2	22.2	35.7	41.3	44.2	46.0
37.9	22.3	35.3	40.8	43.3	45.0
36.6	22.3	35.3	40.6	43.1	44.8
35.7	22.3	35.2	40.6	43.1	44.8
30.2	20.8	38.0	42.9	46.2	48.3
28.5	20.8	37.4	45.1	48.8	51.2
26.7	21.4	40.2	49.4	53.8	56.5
25.1	21.9	43.8	54.3	59.6	63.0
23.8	21.4	44.7	57.8	64.3	68.2
23.0	21.0	45.2	59.3	66.5	70.9
19.5	19.3	45.8	67.0	80.4	87.3
16.7	15.2	40.8	71.3	91.3	101.8
15.3	4.3	11.2	20.5	31.8	44.6

TABLE 63.—*Progressive states of magnetizability, varying with hardness.*[Thin wire, $2\rho=0.084$ centimeter.]

Mean hardness (galvan).	Mean specific magnetism m , for the dimension-ratio =				
	20	40	60	80	100
37.9	31.5	42.6	46.9	48.9	50.2
35.5	30.5	41.3	45.4	47.2	48.3
33.9	30.1	40.7	44.8	46.5	47.6
33.1	29.9	40.5	44.6	46.3	47.4
32.5	29.8	40.3	44.5	46.3	47.4
28.5	29.5	42.6	47.3	49.8	51.7
27.4	30.1	44.8	49.8	52.7	54.5
26.0	32.3	48.6	54.4	57.2	59.4
24.8	33.9	52.6	59.2	62.6	64.7
23.9	34.8	55.3	63.2	67.1	68.9
19.7	32.6	68.8	79.6	86.4	90.7
19.1	28.0	65.8	83.0	92.7	99.0
18.1	6.0	24.5	45.3	61.4	72.2
15.1					

On the basis of these tables the two families of curves, Figs. 17 and 18, have been constructed.



FIGS. 17 and 18.—Relation between specific magnetism and hardness of steel for different diameter ratios.

Magnetism and dimension-ratio.—Of equally great interest, moreover, is the other phase of these phenomena in which magnetizability is regarded as a function of the independent variable, the dimension-ratio, whereas hardness appears merely as an arbitrary constant. We will endeavor in this place to give an account of our data, sufficiently detailed to admit satisfactorily of a comparison with results of earlier observers. In the absence of a better means of estimating hardness the oxide tints were largely made use of, and the wires examined, therefore, classified as hard, yellow annealed, blue annealed, and soft. In conformity with this method of description, we will attempt to give the parameter (hardness) in our own results, such values as will correspond with the said four States. The following special experiments furnish approximate data for the expression of the degree of hardness corresponding to any given oxide tint in our own galvanic scale:

	Gm / Cm ² , 60° microhm.
Glass-hard	s=45.7
Yellow annealed	s=26.3
Blue annealed	s=20.5
Soft	s=15.9

It is well to note that the logarithmic interval between yellow annealed and blue annealed is about equivalent to the same interval between blue annealed and soft, and about twice as large as that between glass-hard and yellow annealed. Referred to our method of tempering, the values for yellow annealed and blue annealed would agree very nearly with three hours of annealing in aniline vapor (mean s=26.7 and 26.0) and one minute of annealing in melting lead (mean s=19.5 and 19.7), respectively.

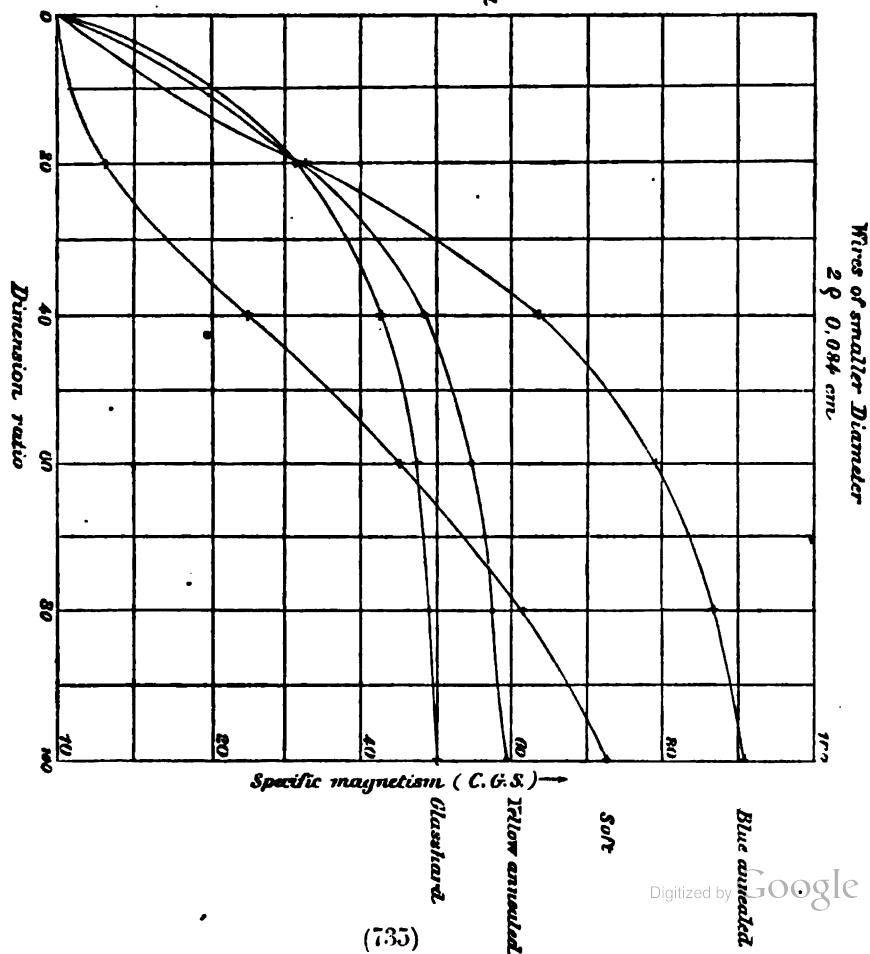
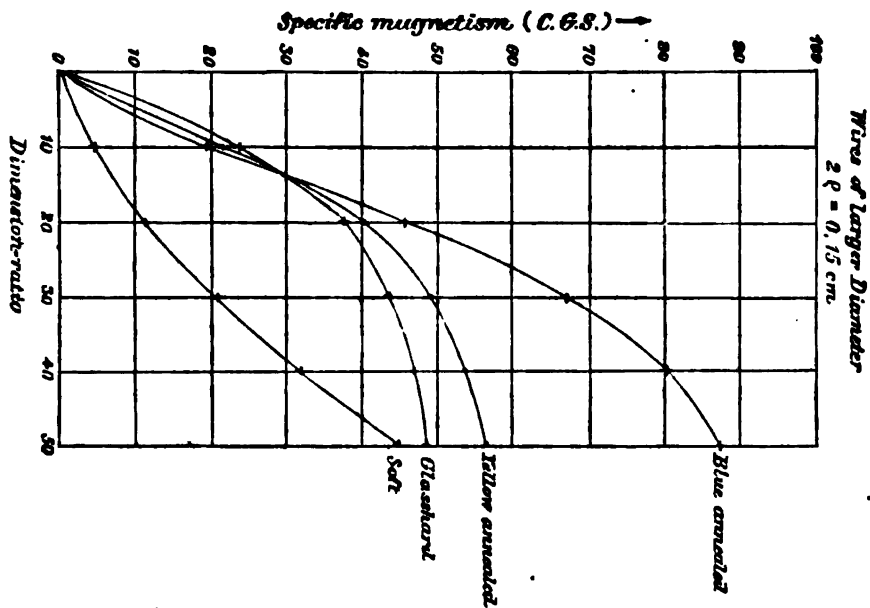
The smaller galvanic values for these states correspond to the smaller values for the soft state (mean s=15.3 and 15.1), respectively, and the difference is, therefore, obviously due to carburization. Hence for our present purposes it is fully sufficient to select from tables 62 and 63 the following mean values of magnetism for the degrees of hardness in question:

TABLE 64.—*Thick wire.*

	Mean specific magnetism m , for the dimension-ratio =				
	10	20	30	40	50
Glass-hard	23.5	37.6	43.6	48.5	48.3
Yellow annealed	21.4	40.2	49.4	53.8	56.5
Blue annealed	19.3	45.8	57.0	80.4	87.3
Soft	4.8	11.2	20.5	31.8	44.6

TABLE 65.—*Thin wire.*

	Mean specific magnetism m , for the dimension-ratio =				
	20	40	60	80	100
Glass-hard	31.5	42.6	46.9	48.9	50.2
Yellow annealed	32.3	48.6	54.4	57.2	59.4
Blue annealed	32.6	63.8	79.0	86.4	90.7
Soft	6.0	24.5	45.3	61.4	72.3



FIGS. 19 and 20.—Relation between specific magnetism and dimension-ratio of steel rods, for different degrees of hardening.

Graphic representation.—These data enable us to construct the curves in Figs. 19 and 20.

The curve glass-hard is concave as regards the axis of abscissæ throughout. Rising very rapidly at first it finally ascends to a distinct limiting value or horizontal asymptote. The curve soft, on the other hand, rises very slowly in its earlier stages, and is convex as regards the axis of abscissæ. From here it passes rapidly upward through a point of circumflexion into concavity towards X, and then above the former curve. Finally the rate of ascent again decreases so that a horizontal asymptote must eventually also be reached, but apparently at a later stage of the progress than is the case with hard wire. From either of these two curves, which describe the variations of the extreme states, we may, by the process of annealing, pass continuously to the other; but the manner of such passage from the one to the other, resulting from a continuous change of parameter (hardness), is excessively complicated. Incipient annealing of a glass-hard rod produces a distinct though small descent of the original curve as a whole. As annealing progresses, the farther end of the curve is always the first to rise and pass above the original curve in such a way that the point of intersection of the new curve and the original curve, glass-hard, moves rapidly from greater to smaller values of the dimension-ratio. When the curve "yellow annealed" is reached the part between $\alpha=14$ or 18, respectively, and $\alpha=\infty$ has already been elevated above the curve glass-hard. In the case of the "blue annealed" curve we observe the part between $\alpha=15$ or 20, respectively, and $\alpha=\infty$ to have risen enormously; but on the other hand the part of this curve between $\alpha=0$ and $\alpha=15$ or 20, respectively, having descended gradually, is now distinctly convex as regards the axis of abscissæ. Passing from blue-annealed to soft, we find the left-hand part of the curve falling at a more rapid rate, while the right-hand branch still rises slowly, reaching a superior limit and then falling rapidly into coincidence with the curve for the soft state, already discussed.

We have remarked that the phenomenon of variation of magnetizability, regarded as a whole, does not by any means seem to present a certain critical value for the dimension-ratio, below which magnets behave differently than above it. If only the four curves hard, yellow annealed, blue annealed and soft were known, as they appear in Figs. 19 and 20, there would appear to be reasons for considering $\alpha=15$ or 20, respectively, as a critical value of this kind; for it is here that the three curves approximately intersect each other. How unjustifiable, however, such conclusions are, will be obvious from a mere glance at Figs. 17 and 18, in which the curves for this value of α manifest no change of character whatever.

Magnetism and density.—We may remark here that when the rod is very long in comparison with its diameter, its specific magnetism (saturation presupposed) becomes constant or independent of the dimensions.

In Green's equation for the distribution of magnetism in a cylinder of finite length, $2l$, and radius r .

$$\lambda = \pi K X \operatorname{pr} \frac{e^{\frac{px}{r}} - e^{-\frac{px}{r}}}{e^{\frac{p}{r}} + e^{-\frac{p}{r}}}$$

where λ is the linear density of free magnetism at a distance x from the middle of the cylinder, K the coefficient of magnetization, X the magnetizing force, p a numerical quantity related to K ; let KX be accepted as the expression for coercive force, F , and put for greater simplicity

$$r \lg \frac{1}{v} = p.$$

If now we evaluate

$$M = 2 \int_0^l \lambda x dx = -\frac{2 \pi p F r}{\lg v} \left[l + \frac{1}{\lg v} \frac{v^{-1} - v^{-11}}{v^{-1} + v^{-11}} \right]$$

and furthermore put

$$m = \frac{M}{\mu} = \frac{M}{\pi r^2 l d}$$

we find that if l (or better $\frac{l}{r} = \alpha$) be supposed to increase indefinitely, m will pass through

$$m = \frac{2 F}{d} \left\{ 1 - \frac{1}{p \alpha} \right\}$$

into a constant value, depending only on the material. Biot¹²² put $p = 0.124$, approximately.

Now it is remarkable that in this case, in which moreover the expression for the linear distribution of magnetism attains its simplest form, we are led to infer that the (linear) rods are capable of retaining more magnetism permanently in proportion as they are softer. But this general deduction will not hold good as far as the soft state. Figure 20 gives as yet no decisive answer to this question. However, in passing from the blue annealed to the soft condition, steel passes through a state of maximum density; and our results thus give warrant to the surmise that the greatest attainable magnetization can be imparted to steel, when the hardness of the necessarily linear rod has that particular value which is characterized by maximum density. This digression suggests itself naturally here, but will be made the subject of a special inquiry. From figure 17, however, it is already quite apparent that the said unique maximum will be considerably larger than 785 c. g. s. units of intensity (magnetic moment per unit of volume), the value thus far assumed and derived from an incidental result of Kohlrausch.¹²³

¹²² Biot: *Traité de Physa*, III, p. 76, 1816.

¹²³ Cf. Gordon: *Electricity and Magnetism*, I, p. 156, London, 1880.

Earlier results interpreted.—It will now be in place to compare our results with those of Ruths. We will select from his data the series contained on p. 47 of his memoir, as these may be regarded typical. Here again, those alone can be considered which refer to magnets as nearly as possible in the permanently saturated state. In the place of the absolute magnetic moment of his steel rods we have deduced the corresponding values for specific magnetism from his data. This greatly facilitates comparison.

TABLE 66.—*Ruths' magnetic results.*

Length = 12.

I.	II.	III.	IV.	V.	VI.	
0.19	0.24	0.29	0.38	0.49	0.59	Diameter.
70	50	40	30	25	20	Dim. ratio, approx.
1.99	4.31	6.22	10.55	17.50	25.65	Mass.
68.7	66.1	74.7	61	66.6	51	Glass-hard.
88.6	71	79.1	52	38.6	29.7	Yellow annealed.
92.0	71	90.2	61.8	48.2	28.4	Blue annealed.

} Spec. Magnetism.

The first comment to be made in this connection has reference to our remarks given in p. 117, on the structural influence of tempering. Ruths' magnets were all of the same lengths, whereas the thickness varied from 0.2 centimeters to 0.6 centimeters. To impart like degrees or similar states of hardness to rods varying in thickness to this very large extent, is manifestly impossible, even if the material were throughout perfectly identical. It follows that the divers values of specific magnetism obtained cannot even be compared one with another. Hence the attempt to arrive at the nature of the functionality between permanent magnetism and ratio of dimensions from these results, must necessarily be futile. Ruths' data are unavailable, therefore, for the construction of curves, corresponding to those in figure 19. We infer from Ruths' table that in general the specific magnetism increases with the dimension-ratio. In the case of the thicker magnets (IV, V, VI) Ruths found values for specific magnetism much larger than our own. In accordance with these, the intersection of the curves glass-hard and blue annealed would occur for $\alpha=30$; the corresponding point for blue annealed and yellow annealed lying at $\alpha=28$. In accordance with Ruths' results, moreover, figure 19 would have to be changed in such a way that the curve glass-hard (to agree with Ruths' large values) rise at a more rapid rate, thus falling short of intersection with the other two curves until these have intersected each other at about $\alpha=20$. Then its passage is through blue annealed at about $\alpha=25$, and through yellow annealed at about $\alpha=40$, where the latter curve is also supposed to rise more rapidly than is the case in our results. But with this apparently satisfactory interpretation, the equivalence of blue annealed and yellow annealed for $\alpha=50$, is wholly in discordance.

Fromme uses eight rods, all of the same length, four of which are of

like small diameter, the other four of like larger diameter, to corroborate Ruths' results. The dimensions are these:

$$\text{First four: } \alpha = \frac{100}{7} = 15; \text{ second four: } \alpha = \frac{100}{2} = 50$$

His results for the ratio of mass (μ) and square of the time (t) of vibration are the following:

		$\alpha=15$	$\alpha=50$
$\mu : t^2$	Glass-hard	1982	413
	Yellow annealed	1506	448
	Blue annealed	1118	440

These values would put the point of intersection of blue annealed and yellow annealed at $\alpha=50$, agreeing with Ruths' result for his magnet II. But this by no means removes the discordance between the data for $\alpha=50$ and those of Ruths for $\alpha<50$, because the latter refer this point to $\alpha=20$.

An extended series of observations on the relation between moment of permanent magnetism and hardness, of exceptional accuracy, has been published by Gray¹²⁴. All the rods have the same dimension-ratio, $\alpha=50$. Unfortunately he does not carry one and the same hard rod through all possible states of inferior temper. Although the material is identical throughout, the results are therefore necessarily distorted by structural discrepancies, in addition to the effects due to differences of hardness in the glass-hard state. In operating with low temperatures Mr. Gray neglects the (then unknown) time-effect of annealing.

In Chapter II, pp. 40-43, we discussed the results obtained with rods tempered in a way nearly identical with that employed by Mr. Gray, hard wires being immersed in linseed oil, the temperature of which was raised very gradually by the aid of a Bunsen flame, and batches of wires removed from the bath at different stages of the heating. If we take into consideration the great irregularity of distribution of temper which the rods so treated manifest, the causes of relatively large discrepancies occurring in Mr. Gray's results are apparent at once. For the same reasons we are not able to compare them in detail with our own.

One striking difference between the two sets of results is, however, to be noticed. Mr. Gray has observed no minimum of magnetizability in the region of glass-hardness. The specific magnetism, in general, is found to increase rapidly between glass-hard and annealed at 100° ; is fairly constant between the latter state and annealed at about 280° ; and after this increases rapidly again until the highest annealing temperature employed (310°) is reached. As a whole, however, the observed range of variation (72 to 80 C. G. S. units of magnetic moment per gramme) is remarkably small when compared with our own (45 to 85

¹²⁴ Gray: l. c.

and 42 to 75, respectively, C. G. S. units of magnetic moment per gramme). The following tabular comparison between Mr. Gray's mean results and our own will exhibit this perspicuously:

Table comparing the mean results of Gray and of B. and S.

[Gray. $l=5.000$, $2p=0.097$ centimeters.]			[B. and S. $l=7.50$ centimeters, $2p=0.15$ centimeters.]				
Rod. No. —	Annealed at—	Mag. mom. (C. G. S.), per gramme.	Rod No.	Annealed at—	During the time.	Mag. mom. (C. G. S.), per gramme.	Hard- ness, $\pm$
1 to 5.....	150°	{ 71.82 74.38					
6 to 10.....	100°	{ 75.64 76.98	IX to XII.	20°		48.3	45.1
			IX to XII.	100°	1 ^h	46.0	46.2
			IX to XII.	100°	8 ^h	45.0	37.9
			IX to XII.	100°	9 ^h	44.8	36.6
			IX to XII.	100°	10 ^h	44.8	35.7
11 to 15.....	150°	{ 75.60 76.50	IX to XII.	185°	20 ^m	48.3	38.2
			IX to XII.	185°	1 ^h	51.2	38.5
			IX to XII.	185°	8 ^h	56.5	38.7
			IX to XII.	185°	7 ^h	63.0	35.1
			IX to XII.	185°	13 ^h	68.2	28.8
16 to 20.....	200°	{ 75.76 76.04	IX to XII.	210°	10 ^m	70.9	28.0
21 to 25.....	240°	77.42					
26 to 30.....	250°	76.89					
31 to 35.....	260°	75.92					
36 to 40.....	270°	77.59					
41 to 45.....	280°	76.51					
46 to 50.....	290°	76.14					
51 to 55.....	300°	{ 78.60 79.09					
56 to 60.....	310°	79.24	IX to XII.	330°	1 ^m	87.3	16.5
			IX to XII.	440°	1 ^h	101.8	16.7
			IX to XII.	1000°		44.6	15.3

The large though unavoidable discrepancies encountered by Mr. Gray, notwithstanding his careful manipulation and precision of measurement clearly show the difficulties with which the problem in question was then surrounded. We possess no data for the magnetic effect produced by tempering in oil. The only satisfactory method of accounting for the above discordance would be that of supposing that Mr. Gray operated upon a less highly carburized steel than was used in our experiments. In such a case, greater values of specific magnetism for the hard state and small values for the soft state in Mr. Gray's results, as distinguished from our own, are anticipative.

CONCLUSION.

The general problem.—The results in this paper offer only a partial solution of the general problem. Irrespective of the effect of carburization, concerning which remarks have already been made, the temporary and permanent magnetization induced by magnetic fields of an intensity insufficient to saturate steel, are new subjects of importance. A fifth

variable, the intensity of the field, therefore, suggests itself. If we remember how intimately magnetic phenomena are associated with the structural condition of a rod, and how absolutely devoid of reliable facts our knowledge of this actually is, we see how little advancement can be hoped from theory. The mathematical analysis, again, even when starting from the simplified premises of homogeneity, encounters formidable difficulties. On the other hand, the possibility of a solution of the general problem, by the application of the method which we have endeavored to develop in the above, we dare say is undeniable. Such an attack we have in view.

Practical bearing.—The present investigation has a practical bearing of some importance. For cylindrical rods it gives a satisfactory solution of the problem as to what degree of hardness is to be chosen in order that a given steel rod may possess the maximum magnetizability. It is a remarkable result, that for very small values of the dimension-ratio considered as one extreme case, the rods can be most intensely magnetized when in the very hard states, whereas for very large values of the dimension-ratio regarded as the other extreme case, similarly favorable conditions are offered by the softer states, with the probability that a state of singular excellence in this respect lies between blue annealed and soft.

But it does not by any means follow herefrom that in the construction of magnets for practical purposes they are to be made glass-hard if short and thick, and soft if long. This question involves elements of quite another character. The problem is so to construct a magnet that with a maximum of intensity it may be best qualified to withstand the hurtful influence of atmospheric changes of temperature, of shocks, and such like effects; in short, to produce a magnet which, under like circumstances, shall always show practically identical values of the intensest available magnetization. This will be made the subject of the next chapter.

ADDENDUM: ON THE DENSITY-EFFECT OF INCIPIENT ANNEALING OF HARD STEEL.

In Chapter V we adverted to the relation probably existing between the maximum of permanent magnetism of linear steel rods and their density. We there, moreover, state the grounds why the conditions most favorable for the appearance of such a relation are encountered in the case of linear rods. The question is therefore immediately suggested whether the characteristic minimum of magnetizability of steel rods corresponds to an analogously singular point in the variation of density. We commenced experiments with the object of discussing the

matter, with a steel rod 1.91 centimeters in diameter and 5.40 centimeters long, tempered glass-hard in the usual way.

State of hardness.	Specific gravity at 20°.	Specific volume.
Commercial.....	7.8320	} 1.00000
	7.8313	
	7.8035	
Glass-hard.....	7.8033	} 1.00363
	7.8032	
	7.8032	
Annealed 1 ^h at 100°.....	7.8040	} 1.00865
Annealed 4 ^h at 100°.....	7.8039	
	7.8052	
Annealed 8 ^h at 100°.....	7.8052	} 1.00339
Annealed 12 ^h at 100°.....	7.8052	
	7.8058	

The first result obtained from these data is a striking corroboration of a result of Fromme's, viz, that the maximum increase of specific volume experienced by a hard-tempered steel rod diminishes as the diameter of the rod increases. Fromme's results for thickness on specific volume of tempered steel rods are these :

$2\rho =$ Thickness (cm.) =	0.7	0.42	0.265	0.255
$v =$ Sp. volume =	1.00772	1.01000	1.01285	1.01210

The result for the above rod $2\rho = 1.91$ and $v = 1.00363$ is in excellent accordance with these data. In drawing this inference it is necessary to bear in mind that serious discrepancies may be introduced by the possible differences in *carburation* of the respective rods. Nevertheless, all these results taken together are so satisfactorily consistent that it is difficult to avoid the deduction made.

The second result shows that the increment of specific volume due to tempering in general decreases as time increases. But this variation takes place at a more rapid rate at the middle stages of the operation than either at its early or closing stages. The curve, therefore, contains a point of circumflexion, and the possibility of a maximum near the inception is by no means excluded. To obtain definite and decisive results, however, it will be necessary to operate with thin rods, for which the density effect of tempering is so much more clearly pronounced.

The plausible inference that the anomalous electrical behavior of steel on incipient annealing, discussed in Chapter II (page 67), and the minimum of magnetizability investigated in this chapter, may find an analogous variation in the density of similarly treated hard steel, cannot as yet, therefore, be said to have been disproved.

CHAPTER VI.

THE TEMPERING OF STEEL CONSIDERED IN ITS BEARING ON THE POWER OF MAGNETIC RETENTION, OR ON THE CONDITIONS OF MAGNETIC STABILITY OF THIS MATERIAL.

INTRODUCTION.

Temporary and permanent magnetic effects of annealing.—The influence of temperature on the moment of permanent magnetism of steel rods is characterized by a temporary and a permanent effect, usually superimposed. If a steel rod magnetized to saturation at the temperature t° is heated to T° ($T > t$) and then again cooled to t° , it will be found to have experienced a loss of magnetic moment. If the process is repeated—the temperatures t and T being the same as before—an additional diminution, decidedly smaller, however, than the first, will manifest itself. Continuing in this way we shall find that the permanent loss converges to zero. The rod is now in a condition for which the magnetization lost during the passage from t° to T° is again restored when the original temperature t° is regained.

Researches on this important subject have been made in great numbers.¹³⁵ The result has usually been that magnets which are to be used between the atmospheric temperatures t and T should be heated and cooled between these or greater limits for an indefinite number of times, in order that a condition of magnetic permanence or of perfect magnetic elasticity, as it has been called, may be assumed.

Simultaneous mechanical effects hitherto disregarded.—To the venture of resuming a topic which has been so elaborately and apparently so exhaustively discussed, we were primarily induced by certain new and important facts which our researches on the hardness of steel had developed. Curiously enough among those who operated with glass-hard rods—and it was to these that we, at first, desired to confine our attention—only a few have given even cursory consideration to the important factor, the change of the mechanical state of the material. We have shown that temperatures 20° or 30° above that of the water in which during tem-

¹³⁵ The earlier literature is systematized in J. Lamont, *Magnetismus*, p. 386, 1867; G. Wiedemann, *Galvanismus*, II a, p. 603, 1874; A. Mousson, *Physik*, 3 Aufl., III., p. 110. Among the more recent papers (since 1876) we desire to mention: G. Wiedeman, *Pogg. Ann.*, CLVII, p. 257, 1876; J. M. Gauguin, *Comptes rend.*, LXXXII, p. 1422; LXXXIII, p. 661, 1876; LXXXVI, p. 536, 1878; G. Poloni, *Beiblätter V*, p. 67, p. 802, and p. 614, 1881; *Elettricità*, II, p. 193, 1878; J. Trowbridge, *Am. Journal* (3), XXI, p. 316, 1881

pering the rod was chilled, when acting on glass-hard rods can be made to produce annealing effects of definite and accurately definable magnitude.

If, therefore, it is our object to investigate the functionality between magnetization and temperature, it is manifestly necessary at the very outset to exclude all permanent and simultaneous changes in the material carrying the magnetic quality. This is what none of the former observers have done. Temperatures as high as 100° are frequently applied. Under these circumstances the hard rod assumes different mechanical properties while in the hands of the operator, and the results will necessarily be stripped of the claims to accuracy which the care frequently bestowed would otherwise justify.

Retentiveness.—There was a second consideration which suggested the present series of experiment. This was the desire to utilize certain earlier data in the endeavor to construct magnets possessing great power of retention. It is not necessary to advert to the important bearing of this problem, not only on all absolute magnetic measurements, but more particularly even on those of a relative character. That the methods now employed are inadequate is conceded by the observers of highest authority and experience. Old magnets subserve best the purposes of measurement; but even these, where a constancy of moment under like circumstances is to be presumed are carefully to be protected from shocks and larger changes of temperature.

The present work.—In the following pages our experiments will be cited chronologically. Some of them are merely corroborative as regards results which have already been pronounced by others. But the intimate connection between these and our subject proper, together with the new interpretation which has frequently been given them, vindicates their appearance here.

The method of magnetization and the calculation of the magnetic moment as well as the measurement of hardness was identical with that detailed in Chapter V.

RETENTIVENESS AS REGARDS VARIATION OF TEMPERATURE.

Preliminary experiments.—Our first experiments were incidentally made with six little steel parallelepipeds, of the same material which had been used in a series of experiments described elsewhere. The dimensions (cm.) and mass (g) of these, after being tempered to glass-hardness, were as follows:

	I.	II.	III.	IV.	V.	VI.
Length	3.0	2.5	3.0	2.5	3.0	2.5
Breadth	0.5	0.5	0.4	0.4	0.3	0.3
Height	0.3	0.3	0.3	0.3	0.2	0.2
Mass	0.328	0.278	0.278	0.232	0.133	0.113

When magnetized with a large Funkler's magnetic battery (50 kilos portative force) of the horseshoe form, these retained the following quantities of specific magnetism :

	I.	II.	III.	IV.	V.	VI.	
$m =$	16.4	12.9	18.6	14.8	23.0	20.7	$\frac{\text{cm}^{\frac{1}{2}}}{\text{g}^{\frac{1}{2}} \text{ sec}}$

Hereupon the magnets were transferred from a water-bath at 15°C. to another at 50°C. and then returned. This was repeated ten times, with an allowance of about ten seconds of immersion for each. After this process the respective values of specific magnetism were found to be—

	I.	II.	III.	IV.	V.	VI.
$m =$	16.1	12.7	18.4	14.6	24.6	20.8

The losses are therefore small—as a rule, only about $\frac{1}{3}$ per cent. The temperature 50° appears to be relatively low in so far as its effect in producing the variation in question is concerned. If it should be our purpose to reach a limiting value in this way the operation would have to be repeated a great number of times. Possibly several hundred repetitions would even be inadequate.

For this reason we decided to continue the work with the aid of higher temperatures. The magnets were exposed in steam. Previously, however, we remagnetized them to saturation. This was done with a large and powerful helix, through which the current of a dynamo-electric machine circulated. The mean intensity of the magnetizing force when referred to the lengths 2.5 cm. to 3.0 cm. of the magnets, and for the current $3.0 \text{ cm}^{\frac{1}{2}} \text{ g}^{\frac{1}{2}}/\text{sec.}$, was found to be—

$$\Sigma X = 885 \text{ g}^{\frac{1}{2}}/\text{cm}^{\frac{1}{2}} \text{ sec.}$$

It is obvious that these powerful forces¹³⁶ were far more than sufficient to effect the saturation.

The magnets were now exposed in steam at 100° for consecutive intervals of 20, 40 minutes, then for 1, 2, 3, and finally 4 hours. After each withdrawal from the steam-bath they were laid aside for some time in a room in which the temperature varied between 10° and 15° . After this we made the measurement of the magnetic moment. The

¹³⁶For divers other data relative to this helix conf. Chapter V.

results of this series of experiments are shown in the following table for *m* :

TABLE 67.—*Limits of magnetic state.*

Description of temper. .	I.	II.	III.	IV.	V.	VI.
Original condition (hard)	18.97	14.90	21.84	17.08	28.70	28.55
Annealed 20" in steam 100°	14.08	10.74	15.80	12.42	20.94	16.06
Annealed 40" more in steam 100°	11.68	9.05	13.45	10.42	17.00	13.22
Annealed 1 ^h more in steam 100°	10.84	8.11	12.21	9.00	15.68	12.22
Annealed 2 ^h more in steam 100°	9.42	7.32	11.21	8.85	14.16	11.04
Annealed 3 ^h more in steam 100°	8.86	7.07	10.68	8.21	13.63	10.24
Annealed 4 ^h more in steam 100°	8.65	6.69	10.20	8.02	12.98	9.91

If these results be constructed graphically, time of exposure as abscissa and specific magnetism (at ordinary temperature) as ordinate, we obtain a series of curves of regular and similar contour. Their general characteristic is that of an initially rapid descent, which as annealing continues is soon retarded until finally an asymptote parallel to the axis *X*, is approximately reached. These results corroborate the older results for the effect of the time of exposure on the variations of the magnetic state of a bar. The phenomena were first studied by Moser and Riess,¹³⁷ somewhat later by Holmgren,¹³⁸ and particularly emphasized by the latter in a way at variance to the views of the former observers. Physicists were inclined, however, to refer Holmgren's apparently anomalous results to other causes,¹³⁹ whereas Lamont¹⁴⁰ pointed out that Holmgren had operated with glass-hard rods, while the magnets of Moser and Riess were untempered. Quite recently G. Poloni¹⁴¹ has given the effect of the time of exposure due prominence. He fails, however, clearly to discriminate between the results obtained in cases of differently tempered bars, or, in other words, confounds the effect due to change of temper with the magnetic effect. We shall show in the sequel that they are entirely distinct and can be separately studied.

Simultaneous magnetic and mechanical effect of annealing.—But there is another inference of greater relevancy to our immediate inquiry. The curves under consideration are strikingly similar to those formerly obtained while investigating the electrical effect produced by a change of temper of steel (annealing).¹⁴² In fact, the analogy is sufficiently evident to induce us to associate the observed decrement of magnetic intensity and the cotemporaneous change of mechanical state of glass-hard rods as phenomena intrinsically related. In other words, we were inclined to regard annealing as the primary, and the diminution of magnetic intensity (in by far the greater part) as the secondary occurrence; or more

¹³⁷ L. Moser and P. Riess: Pogg. Ann., XVII, p. 403, 1829.

¹³⁸ K. A. Holmgren: Acta Soc. Scient. Upsala (3) I; Fortschritte d. Physik, p. 536, 1856.

¹³⁹ Cf., G. Wiedemann: Galvanismus, II a, p. 614, 1874.

¹⁴⁰ J. Lamont: Magnetismus, p. 385, 1867.

¹⁴¹ G. Poloni: Ellettricità, II, p. 139.—Beibl. II, p. 523, 1878.

¹⁴² Strouhal and Barns: Wied. Ann., XI, p. 930, 1880. Chap. II.

accurately, to distinguish between a primary or purely magnetic (permanent) effect of temperature, a *direct* effect; and an *indirect* effect of temperature, due to the influence of the rearrangement of molecules in consequence of mechanical annealing, upon the existing intensity of magnetism of the rod.

With the object of verifying this hypothesis we selected a sample out of our supply of glass-hard rods which, when tested, showed great uniformity of hardness throughout its length. This was broken into two nearly equal parts Nos. 11 and 12.¹⁴³ The constants of each were found to be—

	No. 11.	No. 12.	
Length ...	10.0	10.0	cm.
Mass.....	0.417	0.418	g.

These were now magnetized to saturation with the helix, and then annealed in steam at 100° during consecutive intervals of 10, 20, and 30 minutes, 1, 2, 3, 4, 5, and 6 hours. After each of these we made a determination of hardness using specific resistance s at the atmospheric temperature t as a datum for this purpose. Furthermore, in order to arrive at the desired comparison, No. 12 was remagnetized to saturation after each interval of annealing, whereas No. 11 was tested for specific magnetism in the condition in which it left the annealing bath, that is without repeated magnetization.

The results of these experiments are contained in the following table. The specific magnetism is represented by m^* and m , according as the magnetic datum in question was obtained with or without remagnetization respectively. W here denotes the observed electrical resistance of the respective rods per meter of length at the temperature t , s the corresponding specific resistance (cm./cm.³ 0° microhm).

TABLE 68.—*Diminution of hardness, magnetization, and magnetizability.*

Description of temper.	Magnet No. 11.				Magnet No. 12.				
	W	t	s	m	W	t	s	m	m^*
Glass-hard	0.755	18.2	39.5	62.6	0.761	18.5	39.9	.....	62.5
Annealed 10" in 100°	741	18.7	38.7	59.5	748	18.7	39.1	59.7	62.4
Annealed +20" in 100°	724	20.1	37.6	56.0	728	20.1	38.0	58.2	61.6
Annealed +30" in 100°	708	21.0	36.7	52.6	712	21.0	37.1	57.5	60.6
Annealed + 1 ^h in 100°	680	19.9	35.7	50.0	693	20.0	36.1	56.5	60.2
Annealed + 2 ^h in 100°	671	20.2	34.8	47.8	676	20.1	35.2	56.1	59.5
Annealed + 3 ^h in 100°	656	18.7	34.1	46.1	660	18.7	34.5	56.4	59.4
Annealed + 4 ^h in 100°	646	19.2	33.5	45.1	651	19.0	33.9	56.5	59.3
Annealed + 5 ^h in 100°	639	20.0	33.1	44.8	644	20.0	33.5	56.8	59.1
Annealed + 6 ^h in 100°	634	19.9	32.8	43.8	638	19.9	33.2	56.5	59.0

¹⁴³ The magnets Nos. 1-10, were used in the work detailed in Chapter V.

Mere inspection of this table discovers at once the striking parallelism in the successive values of specific resistance s and specific magnetism m . If the two series of results be represented graphically, time of exposure as abscissa, s and m respectively as ordinate, we obtain (Fig. 21) two curves of an obviously allied character. Indeed there can be

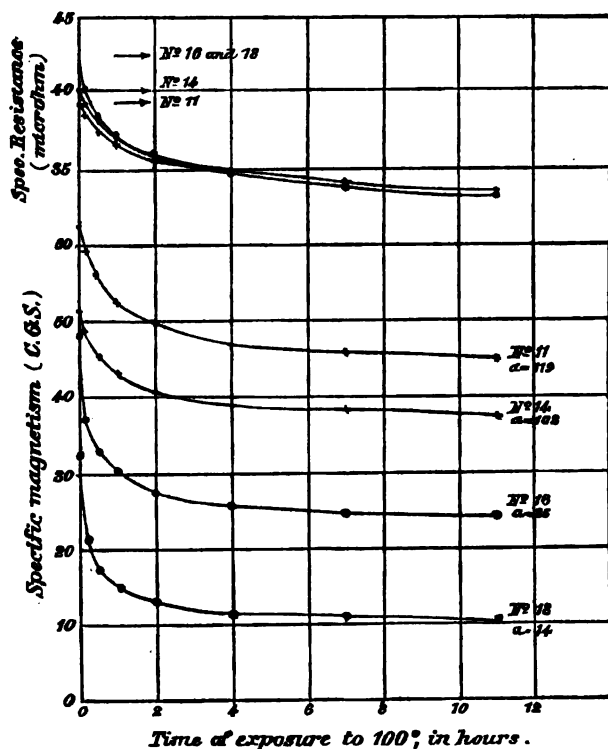


FIG. 21.—Diminution of specific magnetism and specific resistance produced by continued annealing (low temperatures).

no doubt that the occurrence of the continuous diminution of magnetic moment here observed is largely conditioned by the variation of hardness which occurs contemporaneously. It is particularly to be noted that in both instances the asymptotic limit is reached after the lapse of the same time, approximately.

If now we regard the values for m^* as obtained with the magnet No. 12, there appears in the first place a diminution of the quantity of magnetism which the saturated rod permanently retains, which soon however, as annealing continues, reaches a certain minimal value in a way consistent with the results of the former experiments. Furthermore, from a comparison of the values of m and m^* , it follows that during the progress of the annealing the influence of the higher temperature (100°), regarded in connection with the time during which it acts, becomes less and less pronounced, in proportion as the magnet itself has reached

the limiting state of hardness for the temperature (100°) under consideration. But it also appears that the same limiting value of specific magnetism gradually reasserts itself, no matter how often the combined process of magnetization and subsequent indefinite annealing may be repeated. Moreover, a magnet which has approximately reached the limiting hardness for the given temperature, if remagnetized to saturation and annealed again at the same temperature, reaches a limiting magnetic condition, the value of which is nearly independent of the time of exposure.

The purely magnetic effect (permanent).—The inference enunciated at the end of the last paragraph still needs additional proof. Accordingly, our magnets Nos. 11 and 12 were now magnetized afresh and then exposed to steam in the uniform manner described. We thus arrived at the following results:

TABLE 69.—Specific magnetism, m , of saturated rods successively annealed at 100° .

Time of exposure to 100° .	No. 11.	No. 12.
Rods remagnetized	59.0	59.0
10 minutes in steam at 100°	57.3	57.1
20 minutes more in steam at 100°	56.6	56.6
30 minutes more in steam at 100°	55.7	55.9
1 hour more in steam at 100°	55.7	55.6
2 hours more in steam at 100°	55.7	55.6
Rods remagnetized	59.0	59.7
10 minutes in steam at 100°	57.2	57.1
20 minutes more in steam at 100°	56.6	56.4
30 minutes more in steam at 100°	56.0	55.0
1 hour more in steam at 100°	56.0	55.9
2 hours more in steam at 100°	56.0	55.8

We also remagnetized the steel parallelopipedons Nos. I . . . VI, with which the original experiments were made, and then annealed them in steam in the usual way, repeating the whole process a number of times. The following table contains the values of specific magnetism obtained:

TABLE 70.—Specific magnetism, m , of saturated rods successively annealed at 100° .

Time of exposure to 100° .	I.	II.	III.	IV.	V.	VI.
Rods remagnetized	17.82	13.96	20.14	16.22	27.20	22.58
1 hour in steam at 100°	16.34	12.78	18.54	14.75	25.44	21.07
1 hour more in steam at 100°	16.24	12.69	18.33	14.60	25.24	20.93
2 hours more in steam at 100°	16.12	12.66	18.29	14.54	25.12	20.41
Rods remagnetized	17.84	13.94	20.12	16.03	27.40	22.80
1 hour in steam at 100°	16.28	12.69	18.47	14.73	25.42	20.93
1 hour more in steam at 100°	16.24	12.66	18.37	14.69	25.34	20.97
Rods remagnetized	17.77	13.91	20.09	16.00	27.25	22.71
10 minutes in steam at 100°	16.25	12.73	18.31	14.64	25.60	21.01
50 minutes more in steam at 100°	16.10	12.59	18.24	14.54	25.34	20.93
1 hour more in steam at 100°	16.07	12.54	18.26	14.54	25.31	20.86

If the present behavior of the magnets, where the steel has practically reached its limiting mechanical state for 100° , is contrasted with the above, where temper varies simultaneously with magnetism, a much

smaller and thoroughly uniform loss of specific magnetism is everywhere apparent. In the case of No. 11 the original loss amounted to $\frac{62.6-43.8}{62.6}=30$ per cent. nearly; whereas at present the average loss is only $\frac{59.0-55.9}{59.0}=5.3$ per cent. Similarly, the average loss of specific magnetism of the rods I . . . VI was originally $\frac{20.76-9.42}{20.76}=55$ per cent. nearly. Now we have only an average loss of $\frac{19.62-17.93}{19.62}=8.6$ per cent. But owing to the fact that these magnets had been specially treated at the outstart—repeatedly heated from 15° to 60° —an immediate comparison between the last results and those for No. 11 is not to be made.

We have thus arrived at a partial corroboration of certain results obtained by Moser and Riess,¹⁴⁴ and subsequently also by Dufour.¹⁴⁵ Following Moser and Riess, we have for the successive losses of a hard needle:

	Per cent.
After the first magnetization	44.0
After the second magnetization	6.1
After the third magnetization	4.4

But with this last result our observations are at variance. As has been stated, our data have invariably shown that when the maximum of permanent hardness corresponding to any temperature has once been attained, then the magnetic effects of repeated application of the same annealing process are identical, the losses of specific magnetism experienced by saturated rods constant.

The direct and indirect effect of temperature.—We conclude, therefore, that if it be our object to perspicuously represent the law of the phenomena in question, it is essential to discriminate between two species of magnetic loss. If the magnet is in such a condition—for instance glass-hard—that the higher temperature (T) produces a mechanical effect, then this is invariably accompanied by a magnetic effect peculiar to itself, and as experiment has shown, of relatively very large intensity. The reasons for this behavior are obvious. The existence of magnetism is conditioned by a strain of a particular and characteristic kind. The same is true of hardness. It is very probable, therefore, that the partial disappearance of one of these strains from any cause whatsoever will materially interfere with the intensity of the other.¹⁴⁶ Why the influence of the time of exposure to 100° is marked when the state of hardness is such that annealing produces both a mechanical and a mag-

¹⁴⁴Moser u. Riess: Pogg. Ann., XVII, p. 403, 1829.

¹⁴⁵Dufour: Fortschr. der Physik, 1857, p. 438.

¹⁴⁶Whether mere magnetization produces a change in the temper of glass-hard steel is still to be investigated. In consequence of the very small variation of dimensions the anticipative effect must, of course, necessarily be small.

netic effect, is readily seen. For the latter effect must continue to vary until the limit of variation of the former has been fully reached; and the annealing effect of 100° in case of glass-hard steel is a diminution of hardness occurring at a very gradually decreasing small rate through infinite time.

When this has occurred—i. e., when the final state of hardness due to an exposure to T has been reached—we have to do with a purely magnetic phenomenon only. A rod magnetized to saturation and annealed at T° experiences a direct effect—a loss of specific magnetism which is relatively small, nearly independent of the time during which T acts, and the cause of which may be loosely ascribed to a smaller coercive force at T and to the effect produced by the thermal expansion on the magnetic strain. We may add that while in the first case, where the rod itself undergoes a change of state, a limiting value of specific magnetism was not fully reached even after 22 hours of annealing; in the second, the action is certainly complete after the lapse of an hour, and occurs in such a way that the principal part of the magnetism is lost within the first ten minutes.

The reasons fully appear why Moser and Riess found that when soft and annealed rods were used the losses were not only small, but occurred with the characteristic rapidity of those here enunciated. In this case an annealing effect due to 100° is manifestly impossible, and the peculiarities of the purely magnetic phenomenon are alone observed. It would moreover appear that the latter for a given temperature, T , is independent of the material used, of an intrinsically magnetic nature. At least Moser and Riess found for this loss

	Per cent.
When the needle was soft	13.6
When tempered blue	13.4
When tempered cherry red	13.7

We will waive this matter here, as it is our object to investigate it specially, paying particular attention, moreover, to the effect incident upon a variation of the dimensions L/D . Such an effect is already, though somewhat obscurely, apparent.

Pre-existing magnetization.—If the inference derived in the foregoing paragraph be correct, then must it be immaterial whether a glass-hard unmagnetic steel rod is first annealed, say in steam, at 100° , until the final mechanical state for this temperature has been practically reached and then magnetized to saturation, or whether the rod, *originally* saturated, is annealed and then remagnetized, as in the previous case. The ultimate result must, in other words, be independent of pre-existing conditions so long as these are effects of a lower order than correspond to the given temperature.

In order to give this question, which partakes of the nature of a crucial test, due experimental consideration, two rods, Nos. 13 and 14, of equal length, were broken from a glass-hard sample of the same

thickness (0.084 cm.) and material as Nos. 11 and 12. The constants of the new magnets are:

	No. 13.	No. 14.
Length	9.1	9.1 cm.
Mass	0.379	0.381 g.

Of these, No. 14 was magnetized to saturation; No. 13, however, left unmagnetized. Both were then exposed to the action of steam, and the progress of the annealing investigated by repeated measurements of the specific resistances of the rods. Unfortunately, a piece of No. 13 was accidentally broken off in clamping. The new rod (No. 13) was 8.7 cm. long and weighed 0.363 g. The two wires in their present condition would not, however, permit us to discuss the question from a sufficiently broad standpoint, and we, therefore, selected three other wires of the diameter 0.2 cm., so chosen as to present nearly the same specific resistances, viz:

No. V.....	$\epsilon = 42.4$ ($\frac{\text{cm}}{\text{cm}^2}$ $^{\circ}$ microhm.)
No. VI.....	$\epsilon = 42.6$ Do.
No. VII.....	$\epsilon = 42.2$ Do.

The rods were tempered by sudden cooling after heating to redness in the flame of a blast-lamp. Out of the first but a single magnet was taken, No. 15, and but one, No. 16, from the second; while to the third and most homogeneous of the three the two shorter magnets, Nos. 17, and 18, owe their origin. It was intended to have the lengths of Nos. 15 and 16 and of Nos. 17 and 18 identical, but it is difficult in the case of wires of this thickness to break them off at a prescribed mark. Small variations of length are, therefore, unavoidable. The constants of the four magnets (0.21 cm. thick) are:

	No. 15.	No. 16.	No. 17.	No. 18.
Length .cm.	7.2	7.3	2.90	2.95
Mass .....g.	1.90	1.92	0.773	0.776

These were now treated in a manner analogous to that applied to Nos. 13 and 14; 11 hours of annealing in steam at 100° transferred them into the final state of temper for this temperature, not completely, it is true, but sufficiently so for the purposes. All were now remagnetized. Nos. 15, 16, 17, 18, acted on by steam for some time, and their magnetic behavior examined, were then remagnetized again, and once more annealed. Nos. 13 and 14, however, were first exposed to a lower temperature, that of boiling methyl alcohol at 66°, during a certain interval; and not until the magnetic limit for 66° had been fully reached

were they exposed in steam, in order that the limiting value of permanent specific magnetism corresponding to the new temperature (100°) might in its turn appear. The data expressing the magnetic effect of these operations are detailed in the following tables, 71 and 72. As before, W denotes the resistance per meter of length of rod at t° , s the corresponding specific resistances at zero.

TABLE 71.—Limits of magnetic state at 100° .

Time of exposure.	Magnet No. 13.				Magnet No. 14.			
	W	t	s	m	W	t	s	m
<i>Glass-hard.</i>								
	ohm.	C.	microhm.	abs. E.	ohm.	C.	microhm.	abs. E.
0 in 100°	0.734	9.0	39.7		0.741	9.1	40.1	51.4
10 in 100°	721	9.0	39.0		726	9.1	39.3	48.7
+ 20 in 100°	701	9.0	37.9		707	9.0	38.2	45.8
+ 30 in 100°	683	9.0	37.0		688	9.1	37.2	43.4
+ 1 in 100°	666	9.0	35.9		669	9.0	36.1	40.1
+ 2 in 100°	646	9.0	34.9		650	9.0	35.0	39.1
+ 3 in 100°	632	9.0	34.1		634	9.0	34.2	38.
+ 4 in 100°	622	9.3	33.5		626	9.8	33.6	37.
Rod remagnetized				49.9				49.7
1 in 66°				48.3				48.4
+ 2 in 66°				48.0				47.1
+ 3 in 66°				48.0				47.4
1 in 100°				47.5				47.1
+ 3 in 100°				47.5				47.4

TABLE 72.—Limits of magnetic state at 100° .

Time of exposure.	Magnet No. 15.				Magnet No. 16.				No. 17.	No. 18.
	W	t	s	m	W	t	s	m	m	m
<i>Glass-hard.</i>										
0 in 100°								48.1		32.3
One day after tempering	0.1277	8.7	42.4		0.1282	8.8	42.5	47.2		31.6
10 in 100°	1219	9.3	40.4		1218	9.3	40.3	37.4		21.4
+ 20 in 100°	1165	9.6	38.6		1167	9.8	38.6	33.2		17.6
+ 30 in 100°	1128	9.7	37.3		1129	9.7	37.3	30.3		15.2
+ 1 in 100°	1087	9.0	35.9		1084	9.0	35.9	27.8		13.6
+ 2 in 100°	1048	9.1	34.6		1049	9.1	34.7	26.0		11.6
+ 3 in 100°	1021	9.3	33.7		1024	9.5	33.0	24.8		11.2
+ 4 in 100°	1011	10.0	33.3		1008	10.00	33.2	24.5		10.7
Rod remagnetized				43.6				45.3	29.2	30.1
10 in 100°				41.8				43.7	27.8	28.6
+ 20 in 100°				41.7				43.6	27.6	28.2
+ 30 in 100°				41.6				42.6	27.4	28.2
Rod remagnetized				43.4				45.2	29.3	30.0
10 in 100°				42.1				44.0	27.8	28.3
+ 20 in 100°				41.9				43.7	27.6	28.4
+ 30 in 100°				41.7				43.5	27.4	28.4
+ 3 in 100°				41.6				43.4	27.3	28.3

Magnetic effect of annealing—Final result.—In this series of results our views are fully corroborated. When the limiting state of hardness conditioned by the temperature of annealing T has once been reached, then it is wholly immaterial, in so far as the subsequent magnetic behavior is concerned, whether the rod was originally a magnet or not. The consecutive values of m for Nos. 15 and 16, as well as Nos. 17 and 18, after 11 hours of annealing and remagnetization have been applied, manifest a perfectly similar progress throughout. The same is true of Nos. 13 and 14, both while in vapor of methyl alcohol and while in

steam. It will be observed that the limiting magnetic state for 66° differs from that of 100° , although neither is able to effect any further change in the qualities of the material. Whence it follows, in complete analogy with the results formerly found in the case of simple annealing, that in the present case each given temperature, after having been applied to a glass-hard rod to produce and consummate the mechanical effect, and thereupon to the remagnetized rod for magnetic effect, has its particular and characteristic magnetic limit.

*Simultaneous variation of specific resistance and magnetism (low temperature).—*In Fig. 21 the diminution of specific resistance, together with the simultaneous variation of specific magnetism due to annealing at 100° , has been graphically represented. The results are those above given for the magnets Nos. 11, 14, 16, 18. The similarity in the two sets of curves suggests an inquiry into the mutual dependence of these quantities. In figure 22 we have plotted specific resistance as abscissa

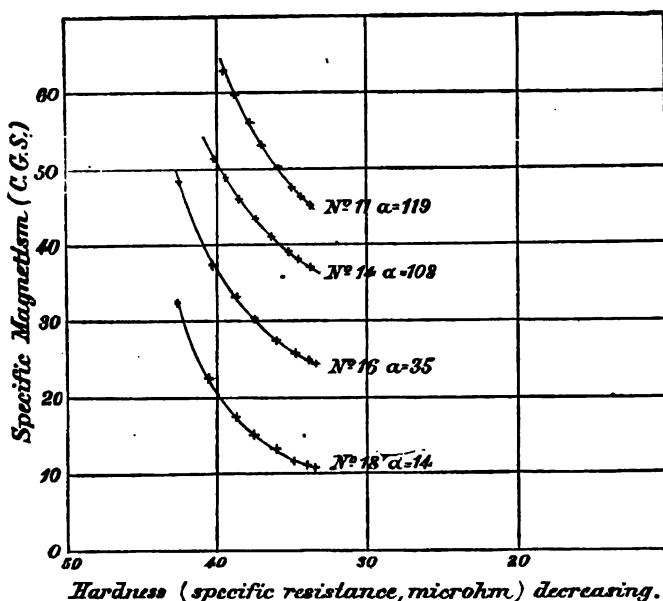


FIG. 22.—Simultaneous variation of specific magnetism and specific resistance in case of continued annealing (low temperatures).

and specific magnetism as ordinate. The points are found to lie on loci of small curvature, approximately parallel to one another. The members of the family appear the more nearly linear the greater $\alpha = \frac{L}{D}$ and therefore the simpler the linear distribution of the magnetism. All are, of course, only the initial parts of far more extensive curves to be obtained by continuing the annealing at temperatures higher than 100° .

The data for Nos. 11, 14, 16, and 17, moreover, show in how far the diminution of specific magnetism from the original to the final value, as

resulting from annealing, is dependent on the ratio of dimensions α . We have the following values for the amounts lost:

No. 11.....	$\frac{62.6-43.8}{62.6}=30$ per cent.;	$\frac{L}{D}=\alpha=\frac{10}{0.084}=119$;
No. 14.....	$\frac{51.4-37.0}{51.4}=28$ per cent.;	$\frac{L}{D}=\alpha=\frac{9.1}{0.084}=108$;
No. 16.....	$\frac{48.1-24.5}{48.1}=49$ per cent.;	$\frac{L}{D}=\alpha=\frac{7.3}{0.207}=35$;
No. 18.....	$\frac{32.3-10.7}{32.3}=67$ per cent.;	$\frac{L}{D}=\alpha=\frac{2.95}{0.207}=14$.

It appears, therefore, that long, thin magnets lose decidedly less than those of small length. But the initial intensity is not without influence. For instance, although both No. 11 and No. 14 were originally saturated, the former retained a larger quantity, whether in virtue of its state of hardness or from small differences of chemical composition does not appear; for the loss of No. 11 is greater, or else that of No. 14 smaller, than the other values would indicate.

In a similar manner the influence of hardness appears in a series of experiments made with ten small steel parallelopipeds of nearly the same dimensions. These magnets (designated by No. VII to No. XVI), 2.5 cm. long, 0.4 cm. broad, and 0.3 cm. thick, of the same material, were glass-hardened in the same way—in so far as this is possible in the ordinary method of tempering—and finally magnetized to saturation by the action of the same magnetic field (helix). The following tabular comparison of the results, however, shows variations of a kind such that few consistent inferences, with the exception of that emphasizing the effect of hardness, can be deduced from them. But from this very fact the importance of structural effects is again clearly indicated.

TABLE 73.—Limits of magnetic state at 100°.

	VII.	VIII.	IX.	X.	XI.
Weight (g).....	2.53	2.45	2.48	2.47	2.52
Specific magnetism:					
Glass-hard, saturated.....	11.18	14.11	14.08	15.11	14.15
4 ^h in steam.....	2.70	2.89	3.93	4.34	4.06
Rods re-magnetized.....	10.05	12.26	12.31	13.25	12.79
2 ^h in steam.....	7.91	11.06	10.93	12.09	11.44
Loss in per cent. of original value (m):					
First loss.....	76	80	72	71	71
Second loss.....	21	10	12	9	11

TABLE 74.—Limits of magnetic state at 100°.

	XII.	XIII.	XIV.	XV.	XVI.
Weight (g).....	2.51	2.41	2.48	2.39	2.43
Specific magnetism:					
Glass-hard, saturated.....	12.47	14.05	14.64	16.56	15.76
4 ^h in steam.....	4.09	3.08	4.53	5.55	4.55
Rods re-magnetized.....	11.50	13.00	13.61	15.72	14.85
2 ^h in steam.....	9.80	11.82	12.45	13.70	13.34
Loss in per cent. of original value (m):					
First loss.....	67	78	69	67	71
Second loss.....	15	9	9	13	10

Specific resistance and specific magnetism—Higher temperatures of annealing.—The following final experiments on the relation between magnetic moment per unit of mass and the respective specific resistance, in case where a diminution of both qualities is effected by annealing, give further insight into the nature of this functionality. Two magnets, Nos. 19 and 20, were broken from a glass-hard rod, No. VIII (diam. 0.147 cm.), and exposed for different lengths of time in hot baths. The constants of the magnets are these:

Length	$L = 1.50$	9.09 cm.
Mass	$\mu = 0.193$	1.172 g
Dimension ratio	$\alpha = 10.2$	61.9

The results obtained by examination at different stages of the operation of annealing are given by the following table:

TABLE 75— *Simultaneous variations of magnetization and galvanic hardness, for continued annealing.*

Magnets Nos. 19 and 20.

Time of exposure.	$W 1 m$	t	s	m No. 19	m No. 20
	<i>Ohm</i>	<i>°C.</i>	<i>microhm.</i>		
Glass-hard	0.283	11.5	47.0	21.25	39.1
20" in 100°	0.267	12.0	44.2	12.56	29.5
+ 2 ^h in 100°	0.245	12.0	40.5	7.74	22.3
+ 10" in 185°	0.202	11.6	33.4	3.93	18.8
+ 6 ^h in 185°	0.162	11.3	26.7	2.45	17.5
+ 1" in 330°	0.120	10.0	19.6	0.25	14.4

These curves (figure 23) pass from convexity as regards the axis x through a point of circumflexion into concavity. Both loci are very

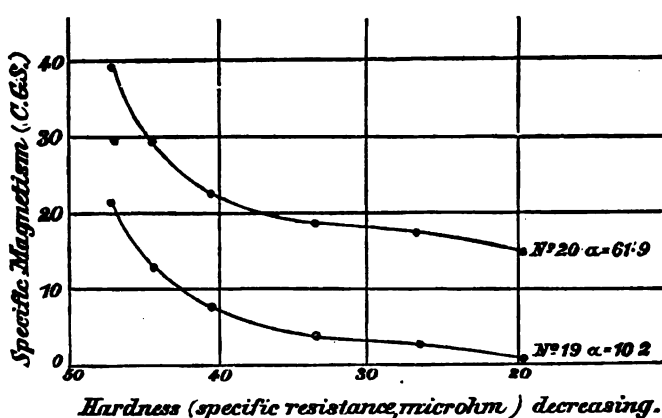


FIG. 23.—Simultaneous variation of specific magnetism and specific resistance in case of continued annealing (high temperatures).

much alike, decreasing rapidly near the origin as well as near their extreme points (annealed at 330°). Short magnets lose their magnetiza-

tion when exposed to temperatures at more rapid rates than long ones. The latter, on the whole, show greater magnetic permanence than the former.

The interpretation of these phenomena is difficult. But it is in place to present the salient points to be considered here. For the reasons given on page 145, a perspicuous relation between magnetism and resistance can only be anticipated in case of linear rods. The results in hand conform with this view to the extent that the observed curvature diminishes in marked degree in proportion as α increases (cf. Fig. 22). In general, moreover, there are two phenomena superimposed: the direct magnetic effect of temperature and a much larger indirect effect, the latter being the magnetic effect of a change of hardness (annealing) produced by temperature, simultaneously. In the case of a given rod (α constant and large) the direct effect is a function of time and temperature. The indirect effect, on the other hand, must be expressible as a function of s since this quantity shows the amount of change of mechanical state. Take rod No. 11, in which α is large, for instance, and deduct the direct effect given in Table 69 from the superimposed effects given in Table 68; the variation of magnetic moment (m') and hardness for the indirect effect alone is given in this table:

Time of annealing.	Direct effect.	Indirect effect.	s
	$m =$	$m' =$	
0	62.6	62.6	39.5
10 minutes	59.5	61.8	38.7
20 minutes	56.0	58.4	37.6
30 minutes	52.6	55.6	36.7
1 hour	50.0	53.6	35.7
2 hours	47.3	50.3	34.8
3 hours	46.1	49.1	34.1
4 hours	45.1	48.1	33.5
5 hours	44.3	47.3	33.1
6 hours	43.8	46.8	32.8

Here, therefore, the relation between m' and s is approximately linear. Thus far, however, magnetizability has decreased; its variation is small.

A passage to higher annealing temperatures is accompanied by a marked *increase* of magnetizability. The actual magnetism possessed by the rod after thorough annealing in the lower temperature (100°), may, therefore, fall so far short of the attainable saturation at a higher temperature as not to be affected sensibly, either by the direct or the indirect influence of the said higher temperature. This inference is substantiated by the data in Table 75 for the rods Nos. 19 and 20. The slight variation of specific magnetism in the case of higher annealing temperatures (185° , 330°) is exhibited in Fig. 23 by the approximately horizontal parts of the corresponding curves. It follows, therefore, that before the relation of magnetism and resistance can be thoroughly discussed, the character of the relation between maximum of permanent magnetism and hardness, which in Figs. 17 and 18 is

graphically given for ordinary temperatures, must be known for all other temperatures. In other words, a family of curves such as given by Figs. 17 to 20 exists with equal definiteness for higher temperatures (100° , 200° , 300° , etc.) and from the co-ordination of such series of families the value of the direct or purely magnetic effect of temperature is deducible for any given circumstances.

Furthermore, the increments of the superimposed magnetic effects and the simultaneous increments of specific resistance should be compared when obtained under circumstances such that the (linear) rod remains, as nearly as possible, in a state of magnetic saturation. It is, therefore, essentially necessary to compare increments. The character of the direct effect being known, that of the indirect effect follows.

It will be observed that the difficulty encountered here is the result of variation of magnetizability. Moreover, the direct and indirect effects need not necessarily vary independently of each other when superimposed.

MAGNETIC RETENTIVENESS AS REGARDS THE EFFECTS OF PERCUSSION AND TIME.

Effects of temperature, percussion, time.—The use of annealed in the place of glass-hard magnets for magnetic instruments, procures for us the decided advantages of a diminished sensitiveness as regards the influence of temperature. If a magnet, which is thus to be used, is annealed at a given higher temperature T° —we will continue to suppose it produced with steam, a method both convenient and satisfactory—until the limit of hardness characteristic of this temperature has been attained, then will this material be perfectly passive in so far as temperatures below T° are concerned. If the rod is then magnetized to saturation—how often soever this may have been previously done is entirely without consequence—and again thoroughly annealed at T° , then the magnet will in a comparatively short interval of time arrive at a stable and limiting magnetic state, which when exposed to temperatures below T° will in its turn be equally passive, *i. e.*, suffer no *permanent* magnetic variations. But where magnets are to be used for purposes of measurement, a full guarantee for their stability as regards permanent effects from changes of atmospheric temperature is not the only desideratum. The efficiency of the magnet is conditioned almost to an equal extent by its power of magnetic retention against such influences as percussion or rapid vibration, or indeed the prolonged effect of time. That the methods previously employed for the construction of magnets for practical purposes are invariably deficient in this respect is well known, and it will therefore be adequate to add in this place a single authoritative statement only.

Observations of Wild.—In the "Annalen des physikalischen Central-observatoriums," St. Petersburg, p. 63, 1878, H. Wild discusses the efficiency of Edelmann's bifilar magnetometer and refers to the magnet of this apparatus as follows:

Obgleich der Magnet nach seiner Magnetisirung abwechselnd einer Temperatur von 0° und 30° ca. 30 Mal ausgesetzt worden war, um ihn permanenter zu machen, fand doch eine schnelle Abnahme des magnetischen Momentes statt, so dass sie mehrfache Verstellungen und Veränderungen erforderte. Damit nämlich die Scala noch nicht ganz aus dem Gesichtsfelde herausrückte, musste schon am 17. April (seit Anfang December) der Torsionswinkel um $1^{\circ} 51'.5$ vermindert werden, um wieder die Mitte der Scala in das Gesichtsfeld des Fernrohrs zu bringen . . . Da die Verminderung des Magnetischen Momentes des Stabes auch in folgenden Monaten ungeschwächt fortdauerte, so befürchtete ich, es sei der Magnet schlecht und liess nach dem Muster desselben einen neuen herstellen.

A numerical estimate of these variations is furnished by the following data: The magnet in question was 8.0 centimeters long, 2.1 centimeters broad, and 0.22 centimeter thick; its magnetic moment M and specific magnetism m were found initially, after the change of temperature mentioned, to be—

$$M=954.2 \qquad m=28.31;$$

after 9 months:

$$M=914.5 \qquad m=27.14$$

The mean loss per month was therefore as high as 0.46 per cent. of the original value, but the new magnet was hardly found to be preferable to the old. On page 8 of the "Annalen des Centralobservatoriums, etc.," 1879, H. Wild reports as follows:

Auch der neue Magnet verlor nach der Aufhängung am Bifilar noch fortwährend bis zum Schlusse des Jahres so viel Magnetismus, dass eine Bearbeitung der Beobachtung an diesem Bifilar nicht erfolgen konnte.

This magnet had also been subjected in the usual manner to 16 successive changes of temperature between 0° and 56° .

The following data show the extent of these variations accurately:

On the 29th of December, 1878, immediately after magnetization the magnetic moment M and the specific magnetism m of the bar were

$$M=1852 \qquad m=55.0$$

Some time after, on the 4th of February, 1879,

$$M=1756 \qquad m=52.1$$

After 16 changes of temperature between 0° and 55° ,

$$M=1694 \qquad m=50.3$$

The explanation of these results on the basis of our investigation is no longer difficult. It was customary—following Riess and Moser, who considered the time of exposure to the higher temperature as of no consequence—to put the principal stress on the condition of a change of temperature. As a result, the magnet was subjected to the influence of the higher temperature only long enough to heat it uniformly throughout. Even Holmgren contended that permanent and hurtful effects of

temperatures between given limits (0° and 100°) could be made to vanish by repeated alternations of temperature from the inferior (0°) to the superior (100°) limit, and with this end in view heated and recooled his magnet fully 213 times. Possibly this might actually suffice. If, however, as is usual, only 20–40 alternations are made (and even this is tedious and troublesome, consuming much time), a sufficiently advanced state of annealing can hardly have been attained. To a much smaller extent even will this be the case where temperatures only as high as 50° are employed. The magnet therefore practically remains in an extreme of glass-hard state, a condition in which strains of an intensity so enormous exist in the rod, that irrespective of other causes, changes of mechanical state purely the results of time may be anticipated. By the process of annealing, these abnormal strains, so to speak, are diminished to values which insure far greater stability of mechanical state.

Better results are obtained by application of higher temperatures than 50° , if the action of these is sufficiently prolonged. For instance, a magnet, destined to become a part of the bifilar at the Physical Institute at Würzburg, was, after magnetization, held for ten minutes in boiling water and then adjusted in place. The original specific magnetism was found to be

$$m = 28.95 \qquad M = 2397$$

After the annealing

$$m = 24.43 \qquad M = 2023$$

Since that time the bifilar has been in continual use, and the behavior is quite satisfactory. If we observe how great is the initial change of hardness, relatively speaking, during the first ten minutes of exposure to 100° , we infer that even this amount of annealing is sufficient to reduce the hurtful excess of strain to a degree that insures fair stability. A constancy of magnetic moment under like conditions is the result.

Obviously, however, results of better permanence will be reached where the annealing at the practically convenient temperature of 100° is sufficiently prolonged to leave the magnet in the limiting mechanical state characteristic of this temperature. But unfortunately such a process would diminish the magnetic intensity very materially; indeed, in the usual case of a ratio of dimensions $\alpha = 10 \dots 20$, a loss of even more than 70 per cent. is frequently met with in the above. If, however, the bar is again magnetized to saturation, the original intensity will be very nearly regained; whereupon, if the process of annealing is once more applied, a limiting magnetic state possessing the desired stability, is reached, with a loss of magnetization amounting to only 5 to 10 per cent.

Maximum hardness and magnetization for 100° , stable at 0° .—Now, there is ample reason for the belief that rods in this singular magnetic state possess the best available qualities of magnetic retention. If a glass-hard saturated magnet be dropped, the result is invariably a loss

of magnetic moment. This is by no means the case with rods subjected to the treatment specified. Even if a sharp blow be intentionally administered, or the magnet be thrown with violence upon the floor, the action is without apparent magnetic effect. As an example we will cite the following observations made with a short and thick magnet. It is known that the retentiveness of such is much inferior to that of long, thin rods.

The magnet was 2.5 centimeters long, 0.4 centimeter broad, and 0.3 centimeter thick. At the outset it was purposely boiled for but 4 hours in water; then magnetized to saturation, and subjected during 2 hours to the action of steam. Our magnetometer showed the following average deflection of five readings (scale-parts millimeters):

$$n = 27.00$$

Then the magnet was placed on a block of wood, and, with the aid of a second block, sharply struck 30 times at right angles to the direction of its magnetic axis, and 20 times in a direction with it. After placing the magnet aside for a time, in order that its original temperature might be reassumed, the reading at the magnetometer was

$$n = 26.97$$

The same process was repeated, with the result

$$n = 26.93$$

Even if the slight diminution from 27.00 to 26.93—about 0.3 per cent.—had existence in fact—that is, was not due to errors of observation, but to magnetic moment lost—still, as it represents the magnetic effect of 100 powerful blows, it is certainly negligible. But this magnet has not yet reached the maximum of permanent hardness for 100°. Whence it follows that, from a rigid application of our method, results more satisfactory even than this are to be looked for.

Experiments of a determinate and final character were made upon a hollow cylindrical magnet, weighing 109.32 g. The length of the tube was 16 centimeters, its outer radius 1.6 centimeters, its inner radius 1.2 centimeters. After tempering to glass-hardness it was magnetized to saturation, then annealed in steam at 100° for a period of 30 hours. After this the cylinder was once more magnetically saturated and thereupon reannealed in steam for 10 hours. The specific magnetism, determined from time to time, showed the following values:

Magnet glass-hard, saturated	$m = 41.0$
10 hours in steam at 100°	$m = 26.1$
20 hours in steam at 100°	$m = 25.2$
30 hours in steam at 100°	$m = 24.8$
Magnet annealed, resaturated ...	$m = 39.9$
5 hours in steam at 100°	$m = 33.8$
10 hours in steam at 100°	$m = 33.1$

In the last instance the needle of our magnetometer for a distance of 72.9 centimeters of the magnet and a rotation of the same of 180° , was deflected over $n=475.6$ scale-parts (millimeters), where 250 centimeters intervened between mirror and scale and the whole measurement was subject to the conditions of Gauss's second position.

The magnet was now introduced into a long and wide glass tube and allowed to fall vertically for a distance of 1.5 meters, impinging on a block of wood. This was done once with the north pole and again with the south pole downward, whereupon the deflection was found to be $n=475.2$ scale-parts, and 10 minutes later $n=475.6$ scale-parts.

We then allowed the same magnet to fall in horizontal position from a height of $\frac{1}{2}$ meter upon the floor. After ten of these descents the magnetometer showed $n=474.7$ scale-parts, and five minutes later $n=475.0$ scale-parts.

Finally the magnet was again introduced into the glass tube and dropped in vertical position from a height of 1.5 meters, with the north and south poles alternately foremost. After ten repetitions of this treatment we observed the deflection $n=473.3$; after three minutes, $n=474.0$; after thirty minutes, $n=475.5$.

The observed difference may therefore safely be referred to temporary thermal variations, partly incident to the percussion experienced by the rod, partly due to contact of the latter with the hand of the operator. A destructive effect due to percussion cannot be said to be apparent at all, despite the intense shocks to which the magnet was exposed. The temperature of the room ($=6^\circ.0$) did not vary during experiment.

After these results, the inference is warranted that the magnetic retentiveness of rods tempered and saturated in the manner set forth will be proof against effects of cold of the same order, such for instance as are met with by observers in the polar regions. Direct researches on this point are contemplated. Whether or not cold is capable of producing a *mechanical* annealing effect is unknown. Certain it is that it would be discernible only by such sensitive methods as are employed in Chapter II. But the marked magnetic effect produced by reduction of temperature has long been understood. Indeed, J. Trowbridge, by the use of carbonic acid and ether, was able to diminish the magnetic moment in this way fully 66 per cent. In the case, however, where a rod is in the magnetically stable condition as regards an elevation of temperature of say 100° , it is altogether probable that if cooled to a similar extent it will continue to possess the desirable quality in question.

We believe, therefore, in the method described, actually to have found a process for the construction of magnets of exceptional constancy and of powerful magnetic retentiveness. In how far this quality may be preserved in the lapse of time, will have to be deferred to the verdict of observers by whom such magnets may possibly be used. How much more reliable and satisfactory measurements made in different parts of the earth will be, when the magnets are no longer liable to injury from

the shocks and blows unavoidably encountered during transportation, needs no further comment.

In conclusion, we desire to add the following rules for the practical construction of magnets:

1. Rods tempered glass-hard are never to be used as essential parts of magnetic instruments.

2. After having tempered the rod in a way that insures a uniformity of glass-hardness throughout its length, expose it for a long time (say 20 to 30 hours; in the case of massive magnets even longer intervals are preferable) to the action of steam at 100° . The operation may be interrupted as often as desirable. The magnet has now reached the highest or hardest of the mechanical states which are no longer influenced by temperatures below 100° .

3. Magnetize the rod, no matter whether originally a magnet or not, to saturation, and then subject it during a period of about 5 hours (in the case of large massive magnets even longer intervals are preferable) to the action of steam at 100° . Then the magnet will have reached the highest and most powerful of the magnetic states which are no longer influenced by temperatures equal to or less than 100° . The magnet is now ready for use.

It may be added that the advantages of using steam are two-fold: In the first place, the process is exceedingly convenient and economical.¹⁴⁴ In the second, it will be remembered that the temperature 100° ultimately leaves the rod in a condition in which the change of capacity for magnetization, as hardness decreases, takes place along the contours of a very flat minimum.¹⁴⁵ Even if slight changes of hardness should subsequently occur, their magnetic effect would be reduced to insignificance, in virtue of the singular variation just mentioned.

ADDENDUM.

RESULTS OF PROF. H. WILD, OF ST. PETERSBURG, WITH REFERENCE TO MAGNETS TEMPERED AND MAGNETIZED BY THE METHOD PROPOSED IN THIS CHAPTER.¹⁴⁶

We are fortunate in being able to cite in this place some results confirmatory of the efficiency of the method for the treatment of magnets proposed in this chapter bearing the authority of Professor Wild. In his work on the absolute value of Siemens' mercury unit, Professor Wild

¹⁴⁴ A flask with a long neck will be found serviceable. The steam condensing in the latter runs back into the bulk of boiling water. Or the suspended magnet may simply be boiled. The prolonged action of steam is in no way deleterious or corrosive. The rods are etched uniformly black and may thus be polished.

¹⁴⁵ Cf. Chapter V, p. 141.

¹⁴⁶ H. Wild: *Mémoires de l'Académie impériale des sciences de St.-Petersb.*, VII^e sér., T. XXXII, No. 2, p. 36.

made use of a large magnet constructed with exceptional care by H. Freiberg, out of "Eibiswalder naturhartem Wolfram-Stahl." Its dimensions (rectangular parallelepipedon) and weight are these: length, 29 centimeters; breadth, 3.6 centimeters; thickness, 1.2 centimeters; weight, 1,030 grams. This magnet was carefully tempered by heating to low redness and sudden cooling in lime-water at 20° . After being magnetized to saturation between the poles of a powerful electro-magnet, it was kept at 100° for 35 hours; thereupon again magnetized and exposed to steam for 10 hours more. The following are the observed magnetic moments (C. G. S.) at 20° :

1883.		
April 27	After the first magnetization	32.60×10^3
April 30	After 35 hours' exposure to 100°	24.56×10^3
April 30	After the second magnetization	31.48×10^3
May 1	After 10 hours' further exposure to 100°	28.18×10^3

On June 21, 1883, at 20° , Wild obtained for the same quantity, 28.8×10^3 . The magnet, despite the treatment which it had experienced, therefore, still lost about 1 per cent. of its total moment, during the intervening three months. But this variation is little more than 0.0001 of the total intensity per day, if the loss were proportional to time. Referred to July 1, however, when the actual measurements were commenced, the said decrement cannot be estimated as above 0.00005 per day—particularly so if it be borne in mind that the diminution in question must gradually vanish at a continually decreasing rate through infinite time, or that a final and definite moment is being asymptotically approached. Indeed, the said limit was practically reached in the second third of July, as the following results show. Wild further remarks that final magnetization of 28 C.G.S. units of magnetism per gramme is to be considered as a satisfactory value. The results in question are as follows:

Date.	$M: 10^3 =$	Differs from the mean by
July 21	28.8018	—
July 22	28.7846	+0.00048
July 26	28.7749	— 54
Aug. 3	28.7760	— 43
Aug. 4	28.7771	— 32
Aug. 5	28.7834	+ 31
Aug. 10	28.7844	+ 41
Aug. 11	28.7754	— 49
Aug. 13	28.7870	+ 67
Mean $M: 10^3 = 28.7803$		± 0.00045

The value for July 21 is not included in this mean.

We venture to remark that with so unusually large a magnet even better results could have been obtained by repeated boiling and remagnetization. In consideration of the dimensions, the decrement of 1 per cent. is by no means surprising. The tubular magnet discussed in the above was operated upon three successive times by our method, before definite adjustment for absolute work. We are not aware, however, whether it will not take some time, in order that a magnet kept at 100° may thoroughly regain the state of molecular equilibrium for 20° .

CHAPTER VII.

A PHYSICAL DEFINITION OF STEEL BASED ON THE ELECTRIC BEHAVIOR OF IRON WITH GRADUALLY INCREASING DEGREES OF CARBURATION.

INTRODUCTION.

Nature of the problem.—A detailed and thoroughly exhaustive study of the problem in hand, viz, in how far the effect of carburation on the galvanic and thermo-electric properties of iron is available for the general classification of iron-carburets, calls for working facilities at a puddling furnace, for instance, or other technically satisfactory agency for the decarburation or carburation of iron. Possibly, however, similar work might be done on a small scale in the laboratory, if the necessarily complicated apparatus or opportunities for constructing the same were at the observer's disposal. These advantages were not within our reach.

The problem is of a kind, moreover, which is apt to mislead the investigator into insuperable and almost infinite complications. To avoid these it is absolutely necessary to conduct the experiments with reference to some thoroughly preorganized plan. In the absence of the above-mentioned metallurgical apparatus we were obliged to content ourselves with commercial products, and the main purpose of the present memoir has therefore been restricted to the development of a plan or scheme of operations for the general and tentative study of the electrical behavior of iron-carburets. These efforts have not been unsuccessful; indeed they appear to be of considerable promise. They have already afforded us a method for the physically exact definition of steel which we regard as important. As a whole, the present chapter furnishes an essential and interpretative sequel to our researches on the hardness of steel.

Electrical manifestation of mechanical properties.—The very remarkable effect of rapid and of prolonged cooling from red heat, respectively, on the physical and chemical properties of iron-carburets has always been a subject of great metallurgical interest.¹⁴⁷ In the case of steel the contrast between the two states or conditions thus produced is particularly well marked and of the greatest practical value. Experience has shown, however, that the said processes may be applied, with much advantage, to most of the other iron-carbon products. It is thus that

¹⁴⁷On Karsten's theory, relative to the nature of these effects, see Percy's Metallurgy, edited by Wedding and others, Vol. II, p. 167, *et seq.*, Braunschweig, 1864.

the question naturally suggested itself to us, whether the remarkable parallelism discovered in the variation of the degree of hardness of steel and its galvanic and thermo-electric properties was not to be considered as only a special case of the behavior of iron-carburets generally, under analogous circumstances. In this respect we believed ourselves justified in predicting that those characteristic mechanical qualities which distinguish steel from other iron-carburets must necessarily be sharply outlined in a general electrical diagram adapted to the classification of iron-carburets as a whole. A similar idea, as we subsequently found, seems incidentally to have occurred to Joule,¹⁴⁸ since he remarks, after having given the necessary experimental data: "I believe the excellence of the latter metal (steel) might be tested by ascertaining the amount of change in thermo-electric condition which can be produced by the process of hardening." But neither Joule nor others have given the subject more than this inadequate consideration, and it was not until our investigations on steel had been fully developed that the problem attracted our attention.

Critical operations.—At first sight a comparison of the electrical intervals comprehended between the hard tempered, and soft annealed states, appeared to be rich in promise; but the processes of slow and of most rapid cooling possible, from red heat, are as yet not sufficiently defined, even if we abstract from decarburization, etc., for obtaining iron carburets in two characteristic physical states. In the case of slow cooling the temperature in red heat to which the specimen has been exposed, as well as the time during which exposure takes place are important items, particularly when the cast-irons are under examination. In the case of rapid cooling the temperature to which the red-hot rod is suddenly and permanently lowered is additionally to be considered. It would not, however, be difficult to define the two processes in question succinctly. A rod, for instance, suddenly chilled from red heat in water at ordinary temperature and then annealed by long exposure in ether vapor at 35° might appropriately be termed glass-hard; if annealed in vapor of sulphur (500°) or of cadmium (700°), soft. For the very large and physically important class of iron-carburets, wrought-iron, low-carbureted steel, and steel, these details, fortunately, do not produce any serious distortions; the thermo-electric hardness and the specific resistance of steel, no matter what the process may have been by which a given rod was softened, remain very nearly constant in value—at least when compared with the enormous range of variation of these qualities due to tempering. The same is true for the hard condition of the carburets between iron and steel, where it is only necessary to choose the temperature before sudden cooling sufficiently high to insure the appearance of hardness, and to chill in water at ordinary

¹⁴⁸ Joule: Phil. Trans. 1859, I, p. 96.

room-temperature. Decarburization is, however, under all circumstances to be avoided,¹⁴⁹ and the exposures to high temperature must not be prolonged. It follows therefore that it will be expedient to commence the present investigation by a consideration of the electrical properties of the carburets in question, that is such in which the total carbon is less than about 2 per cent. To this may be added that within the interval (0—2 per cent.) those modifications in the mode of occurrence of the carbon in iron, which are the cause of such great diversity in the character of the different species of cast iron, are as yet comparatively without marked influence. Thus it appears that our results for this set of products may be considered as satisfactory and definite. In order to complete the discussion conveniently, however, it is desirable to include certain essential properties of the cast-irons, or in other words to prolong the loci of our diagrams into the region of cast-iron, without going into any details. That this is readily possible will appear in the sequel.

A further introductory remark may be added here. Commercial iron-carburets are never pure, but contain in greater or smaller amounts vitiating impurities like phosphorus, sulphur, silicon, and the like. Each of these produces its own electrical effect, as has been seen in the earlier chapter (III) on alloys. The discrepancy thus introduced need not by any means be negligible, and full consideration is given to it in a later paragraph. For the present it will be expedient to suppose this secondary electrical effect to be absent, or that the material in hand is a pure iron-carbon product.

Nomenclature.—As a convenient nomenclature to be used throughout, we will designate the process of *softening* steel, that is cooling from red heat as slowly as necessary by the Roman numeral “*I*”; the process of sudden cooling from the same temperature (*hardening*, tempering, glass-hard) by the Roman numeral “*II*.” In like manner all constants which refer to *I* or *II*, are to be marked with the subscript 1 or 2, respectively. For instance, $h_1, s_1 \dots h_2, s_2 \dots$ In like manner we may, without confusion, consider “soft state” and “glass-hard state,” “state *I*” and “state *II*,” respectively identical, etc.

¹⁴⁹ In this place it is well to call to mind an important result of Forquignon's (Ann. de Chim et de Phys. (5) XXIII, p. 538, 1881). He found that steel kept at red heat for seventy-two hours, in an envelope of hematite, lost nearly one-half of its total carbon. This corresponds to the loss of nearly four-fifths of total carbon, due to continued exposure of cast iron to red heat in the preparation of malleable cast iron (Percy op. cit., p. 143.) In many physical experiments with steel, particularly in magnetic work, it is often necessary to soften steel by heating it to redness for some time. It is therefore obvious that the product thus obtained cannot be considered identical, as regards total carburization, with the original carburet. Possibly this method of eliminating carbon may be available for obtaining points in an electric diagram corresponding to iron-carburets lying between iron and steel.

WROUGHT-IRON.

Electrical data.—Pure iron subjected to the process *II* is mechanically indistinguishable from the same metal when subjected to *I*. So also the electrical difference between these two states is practically insignificant. This is true approximately for commercial iron with less than 0.2 per cent. of carbon, and the more nearly true, moreover, the smaller the amount of this element.

For the electrical conductivity of iron Chwolson¹⁵⁰ gives the following results: If a hard-drawn wire is ignited at low redness its electrical resistance is found to vary about -0.4 per cent. If the ignition be intense about $+5.3$ per cent. The process *II* produces a variation of only 0.7 per cent. in comparison with the hard-drawn state. If, therefore, we compare the rod in the state *II* with the same rod in the state *I*, we find a total electrical change about $+1.1$ per cent. or -4.6 per cent., respectively, according as *I* was produced by gentle or by intense ignition.

For results of this kind, with reference to the thermo-electric behavior of iron, we searched in vain. But the relation between the variations of thermo-electric and galvanic constants is initially (*i. e.* for very small amounts of a foreign element alloyed to any given metal) linear, as we proved both in the case of steel and of alloys of silver. Hence results of the same order as Chwolson's may be at once predicted for the thermo-electric behavior of commercial iron. Sir William Thomson¹⁵¹ found that the thermo-electric hardness¹⁵² of iron, like that of steel, is increased by the process *II*. Joule¹⁵³ finally remarks, "I find that in steel the (thermo-electric) change is in the same direction as in iron, but of enormously greater magnitude."

These small variations amounting to less than 2 per cent. of the total resistance or thermo-electric hardness, are for the present purposes at least, quite negligible; particularly so when contrasted with the corresponding change of the electrical constants of steel (200–300 per cent.). Where great accuracy is sought for, special measurements may be made. For this reason we accept for wrought iron the values for the electrical constants given in the following table (76). Here thermo-electric hardness is represented by h , specific resistance by s ; h_1 refers to iron subjected to process *I*; h_2 to the same wire subjected to process *II*, etc., as has been stated. Furthermore $\Delta h = h_2 - h_1$; $\Delta s = s_2 - s_1$; $\Delta \log$

¹⁵⁰ Chwolson: Bulet. de St. Petersb., X, p. 379, 1877; also Carl's Rep., XIV, p. 26, 1878.

¹⁵¹ Thomson: Phil. Trans., 1856, III, p. 722.

¹⁵² On the definition of thermo-electric hardness, see our paper in Wied. Ann., XI, p. 970, 1880, or this memoir, Chapter II, p. 65.

¹⁵³ Joule: Phil. Trans., 1859, I, p. 96–97.

$h = \log h_2 - \log h_1$; $\Delta \log s = \log s_2 - \log s_1$. The object of these differences will appear below. For h and s the values obtained elsewhere¹⁵⁴ are given. Microvolts, microhms, and square centimeters are the fundamental units: $\log$ refers to Brigg's logarithms.

TABLE 76.—Electrical constants of wrought-iron.

Material.	Thermo-electric hardness.		Specific resistance.		Δh	Δs	$\Delta \log h$	$\Delta \log s$
	h_1	h_2	$s_1 \frac{\text{cm}}{\text{cm}^2} ^\circ\text{C}$	$s_2 \frac{\text{cm}}{\text{cm}^2} ^\circ\text{C}$				
Wrought iron.....	Microvolt. 4.7	Microvolt. 4.7	Microhm. 12.2	Microhm. 12.2	Zero.	Zero.	Zero.	Zero.

STEEL.

Electrical data.—If we suppose the degree of carburization of iron to increase continuously from zero to about 1.5 per cent., the difference in mechanical hardness between states *I* and *II* will likewise increase continuously until steel is reached. For the purpose of defining the relatively enormous interval peculiar to the latter substance technically, metallurgists are in the habit of using some empirical criterion—for instance, the power to give sparks with flint.¹⁵⁵ It is, moreover, of the greatest practical importance that this phenomenal change of mechanical condition is confined to state *II*, and that state *I*, as regards hardness at least, is not readily distinguishable from wrought iron.

A large number of results on the electrical behavior of steel were discussed above. It will therefore only be necessary, in this place, to recall to mind the electrical interval *II*–*I* for this substance in a table constructed on the plan of the preceding, and therefore needing little further elucidation. For state *II* the largest values¹⁵⁶ occur in case of rod No. 28.

$$h = 17.7 \text{ and } s = 41.5$$

But later experiments¹⁵⁷ furnished considerably harder wires, the results

¹⁵⁴ Chapter II, p. 61. The mean values for the three iron wires there examined are here given.

¹⁵⁵ Cf. Karsten: Karsten's und v. Dechen's Archiv, XXV, p. 223 et seq., 1853; also Jeans, "Steel, its history," etc., London, Spon, 1889, pp. 533–542.

¹⁵⁶ Cf. Chapter II.

¹⁵⁷ See our paper, Wied. Ann., XX, p. 640, 1883.

for which are not given in the digest in question. The hardest of these showed $s=47.5$. If we put $h=ns$, there follows,

$$h=19.6 \text{ and } s=47.5$$

The minimal values for state *II* are those of rod No. 39:

$$h=15.1 \text{ and } s=34.9$$

The largest values for state *I* are given by No. 46:

$$h=6.9 \text{ and } s=16.0$$

and the smallest by No. 47:

$$h=5.0 \text{ and } s=14.0$$

The following table (77) contains both extreme and mean values for the different constants, the largest being put on the horizontal row *l*, the smallest on the row *s*, the mean on the row *m*. All of these are obtained from a combination of the data just cited.

TABLE 77.—*Electrical constants of steel.*

	Thermo-electric hardness.		Specific resistance.		Δh	Δs	$10^8 \times \Delta \log h$	$10^8 \times \Delta \log s$
	h_1	h_2	$\frac{\text{cm}}{s_1 \text{ cm}^2} 0^\circ$	$\frac{\text{cm}}{s_2 \text{ cm}^2} 0^\circ$				
<i>l</i>	<i>Microvolt.</i> 5.0	<i>Microvolt.</i> 19.6	<i>Microhm.</i> 14.0	<i>Microhm.</i> 47.5	14.6	33.5	.....	.....
<i>s</i>	6.9	15.1	16.0	34.9	8.2	18.9	.....	.....
<i>m</i>	6.0	17.8	15.0	41.2	11.8	26.2	460	440

From the remarks made in the above it follows obviously that the magnitude of the interval *II-I* will depend very essentially on the degree of carburization of the steel tested. We experimented with silver steel¹⁵⁸ of excellent quality. But commercial varieties of steel may be readily found in which the said interval *II-I* is even less than one-half that given in the table.

CAST-IRON.

Thermo-electric data.—In his experiments on cast-iron Joule¹⁵⁹ found that the difference of thermo-electric position between state *I* and state *II* is about $\frac{1}{360}$ of the thermo-electric interval bismuth-antimony. In case of steel he found the change of thermo-electric position *II-I* to be in the same sense as in cast-iron and as large as $\frac{1}{15}$ of the said interval. Furthermore, "that the metal (cast-iron) is brought nearer bismuth (i. e., thermo-electric hardness is increased) as the quantity of carbon in combination is increased," and in much larger ratio than would be commensurate with the additional amounts of carbon.

¹⁵⁸ For silver steel see Percy, op. cit., pp. 237-240; also Faraday and Stoddard, Quar. Jour. Science, 1820, p. 325.

¹⁵⁹ Joule: l. c., p. 96.

As accurate a knowledge as possible of the electrical qualities of cast-iron is a matter of such importance as to call for a special examination of a variety of products. These were made with as much material as we found available. The results for thermo-electric power are given in the following tables (78-79), where e denotes the electromotive force referred to silver in microvolts, observed or calculated as specified, corresponding to the temperature T and t of the junctions. On the basis of the formula of Avenarius, $e = a(T - t) + b(T^2 - t^2)$, the constants a and b were calculated, usually from five sets of observations, by an application of the method of least squares. In how far the measurements are satisfactory may be seen by consulting the column of differences (Diff.) between e observed and e calculated. Rods No. 1, 2, 3 were of German cast iron; No. 1 soft and of excellent quality; Nos. 2 and 3, though also of good iron, so hard¹⁶⁰ as not to yield readily to a file. White cast-iron cannot be put in the form necessary for measurements like the present without encountering very great mechanical difficulties. But its properties are well represented by rods Nos. 2, 3, which were specially cast thin. Rods No. 4 . . . 12 are of good American cast-iron, so soft as to be easily touched with a file. They were planed down to approximately square and uniform sections for us by Mr. William Grunow, of New York. All the rods were examined in three states: the original or commercial condition in which they reached our hands; after sudden cooling from red heat (II); after annealing soft at red heat (I).¹⁶¹ We considered chemical analyses superfluous for the reasons given near the beginning of this paper. A few isolated results of this kind are valueless.

TABLE 78.—Thermo-electric power of cast-iron. German material.

Rod.	Remarks.	t	T	e observed.	e calculated.	Diff.	a	b	
		° C.	° C.	microvolt.	microvolt.				
1	Original condition, soft	19.2	83.4	—385.5	—380.4	0.9	—4.94	—0.0105	
		19.8	70.1	—296.9	—296.0	—0.9			
		19.9	59.9	—230.8	—231.1	0.3			
		20.1	50.2	—171.7	—171.0	—0.7			
		20.3	40.2	—110.7	—111.0	0.3			
	Suddenly cooled (II), hard..	15.7	59.9	—343.2	—342.8	—0.4	—7.04	—0.0095	
		15.9	51.6	—274.1	—274.1	0.0			
		16.0	44.4	—215.8	—216.1	0.3			
		16.1	37.9	—164.3	—164.7	0.4			
		16.2	32.2	—120.3	—120.0	—0.3			
	Annealed at red heat (I).....		Rod broken. Too short for measurement.						
	Original condition, hard.....	16.7	76.9	—512.6	—512.8	—0.3	—7.80	—0.0067	
		16.7	69.5	—446.2	—446.6	0.4			
		16.8	59.7	—360.2	—360.1	—0.1			
		16.8	49.9	—275.5	—275.7	0.2			
		16.8	39.1	—184.2	—184.1	—0.1			

¹⁶⁰ Rods Nos. 2 and 3 being only 0.2 . . 0.3 cm. in diameter, it was found impossible to cast them without the appearance of a steel-like and brittle hardness.

¹⁶¹ Cf. Chapter II, p. 60.

TABLE 78.—*Thermo-electric power of cast-iron. German material—Continued.*

Rod.	Remarks.	t	T	e observed.	e calculated.	Diff.	a	b
		° C.	° C.	microvolt.	microvolt.			
2	Suddenly cooled (II), hard...	18.1	55.2	-339.7	-341.0	1.3	-2.30	-0.0121
		18.1	49.6	-289.2	-287.5	-1.7		
		18.0	44.7	-236.4	-237.1	0.7		
		18.0	39.3	-192.4	-191.7	-0.7		
		18.0	34.8	-149.8	-150.3	0.5		
	Annealed at red heat (I), hard	17.5	84.5	-551.9	-551.7	-0.2	-2.84	-0.0126
		17.5	74.5	-461.6	-461.6	0.0		
		17.6	68.9	-368.1	-368.3	0.2		
		17.6	54.8	-261.4	-261.3	-0.1		
		17.7	42.9	-193.3	-193.3	-0.1		
3	Original condition, hard	17.8	79.8	-523.0	-527.2	1.2	-2.08	-0.0043
		17.9	70.8	-444.4	-448.2	1.8		
		18.0	59.7	-354.5	-350.9	-3.6		
		18.1	49.3	-261.1	-261.3	0.2		
		18.2	39.6	-187.6	-178.3	0.7		
	Suddenly cooled (II), hard ..	17.9	53.8	-377.2	-377.3	0.6	-2.12	-0.0145
		17.9	52.6	-318.4	-317.4	-1.0		
		17.8	46.1	-255.7	-256.1	0.4		
		17.8	38.9	-189.0	-188.8	-0.2		
		17.8	32.0	-140.1	-140.2	0.1		
	Annealed at red heat (I), hard	18.0	83.2	-569.2	-568.4	-0.8	-2.61	-0.0149
		18.0	78.6	-481.6	-482.6	1.0		
		18.1	66.4	-376.7	-377.1	0.4		
		18.1	52.2	-259.6	-259.1	-0.5		
		18.1	44.9	-200.6	-200.8	0.2		

TABLE 79.—*Thermo-electric power of cast-iron. American material.*

Rod.	Remarks.	t	T	e observed.	e calculated.	Diff.	a	b
		° C.	° C.	microvolt.	microvolt.			
4	Original condition, soft	24.0	89.0	-500	-499	-1	-5.88	-0.0158
		24.4	74.7	-374	-375	1		
		25.0	49.9	-175	-176	1		
		25.1	39.9	-103	-102	-1		
		22.3	31.6	-56	-56	0		
	Suddenly cooled (II), hard ..	20.5	55.6	-245.0	-244.7	-0.3	-2.42	-0.0073
		20.4	49.5	-201.5	-201.6	0.1		
		20.2	43.5	-159.0	-160.4	1.4		
		20.2	38.9	-129.0	-128.1	-0.9		
		20.1	32.4	-83.5	-83.6	0.1		
	Annealed at red heat (I), soft	19.1	83.7	-423.7	-423.7	1.0	-4.42	-0.0163
		19.1	77.5	-351.2	-349.5	-1.7		
		19.1	62.1	-246.0	-246.6	0.6		
		19.2	53.8	-193.0	-193.8	0.8		
		19.3	42.1	-123.8	-123.4	-0.4		
5	Original condition, soft	12.8	80.8	-486	-484	-2	-5.96	-0.0123
		18.1	68.0	-380	-382	2		
		13.4	56.0	-290	-290	0		
		12.7	47.0	-224	-223	-1		
		12.9	35.2	-140	-140	0		
	Suddenly cooled (II), hard ..	13.5	55.8	-315.6	-317.1	1.5	-2.73	-0.0104
		14.0	49.8	-268.2	-266.4	-1.8		
		14.3	39.6	-184.6	-185.6	1.0		
		14.6	33.4	-137.5	-136.8	-0.7		
		15.0	27.6	-90.7	-91.0	0.3		
	Annealed at red heat (I), soft	16.0	79.0	-390.5	-361.3	0.8	-4.21	-0.0161
		16.4	65.7	-274.5	-272.4	-2.1		
		16.7	56.6	-213.1	-214.8	1.7		
		17.0	43.9	-140.1	-139.4	-0.7		
		17.4	35.3	-90.3	-90.5	0.2		
6	Original condition, soft	14.9	83.2	-462	-462	0	-5.32	-0.0146
		15.3	75.4	-399	-400	1		
		15.5	63.2	-310	-309	-1		
		15.6	50.0	-215	-216	1		
		15.7	39.6	-147	-147	0		

TABLE 79.—*Thermo-electric power of cast-iron. American material—Continued.*

Red.	Remarks.	t	T	observed.	calculated.	Diff.	a	b
		°C.	°C.	microvolt.	microvolt.			
6	Suddenly cooled (II), hard...	14.4	57.7	-270.6	-269.7	-0.9	-5.17	-0.0147
		15.0	48.9	-204.6	-207.1	0.5		
		15.3	40.7	-151.4	-152.3	0.8		
		15.9	34.8	-111.7	-111.8	0.1		
		16.2	22.4	-77.4	-77.1	-0.3		
	Annealed at red heat (I), soft	22.8	83.3	-361.2	-361.6	0.4	-4.27	-0.0161
		23.0	75.2	-308.0	-305.4	-2.6		
		23.0	63.2	-225.5	-227.4	1.9		
		23.0	53.8	-168.7	-169.5	0.8		
		23.0	41.5	-98.3	-98.1	-0.7		
7	Original condition, soft	18.2	71.9	-372	-371	-1	-5.73	-0.0133
		18.3	67.3	-335	-336	1		
		18.4	58.8	-273	-272	-1		
		18.6	51.3	-217	-217	0		
		18.6	44.5	-170	-170	0		
	Suddenly cooled (II), hard, warped.	14.7	57.9	-321.2	-320.4	-0.8	-4.20	-0.0155
		15.2	50.6	-260.0	-258.8	-1.2		
		15.6	43.0	-195.2	-197.3	2.1		
		16.0	37.1	-149.5	-150.1	0.6		
		16.4	31.7	-108.6	-107.7	-0.9		
	Annealed at red heat (I), soft	21.4	82.6	-350.0	-352.9	-0.1	-4.23	-0.0148
		21.4	69.4	-273.3	-272.1	-1.2		
		21.6	56.5	-198.5	-191.2	1.7		
		21.6	47.0	-135.6	-135.6	0.0		
		21.6	39.5	-94.0	-92.6	-0.4		
8	Original condition, soft	17.4	86.9	-502	-500	-2	-5.34	-0.0173
		17.4	80.5	-445	-447	2		
		17.4	72.3	-382	-381	-1		
		17.0	52.9	-236	-236	0		
		17.0	38.9	-139	-139	0		
	Suddenly cooled (II), not very hard.	17.5	57.1	-261.6	-259.8	-1.8	-5.00	-0.0120
		17.9	50.8	-212.0	-213.3	1.3		
		18.2	45.3	-172.1	-173.9	1.8		
		18.7	40.1	-137.2	-136.0	-1.2		
		19.0	35.4	-103.4	-103.3	-0.1		
	Annealed at red heat (I), soft	10.5	87.7	-437.3	-436.9	-0.4	-4.03	-0.0166
		10.8	75.3	-350.7	-352.0	1.3		
		11.1	62.9	-274.8	-273.8	-2.5		
		11.2	52.0	-205.7	-207.2	1.5		
		11.5	42.7	-154.1	-153.7	-0.4		
9	Original condition, soft	12.7	72.3	-411	-411	0	-5.72	-0.0123
		12.8	64.0	-347	-347	0		
		12.8	52.2	-282	-261	-1		
		12.9	43.0	-195	-196	1		
		12.9	37.0	-154	-154	0		
	Suddenly cooled (II), hard, fissured, warped.	18.9	58.3	-300.4	-299.5	-0.9	-6.54	-0.0127
		19.2	52.6	-251.1	-251.4	0.3		
		19.5	44.9	-187.2	-183.7	1.5		
		19.9	37.1	-126.6	-126.0	-0.6		
		20.2	33.6	-97.5	-97.0	-0.5		
	Annealed at red heat (I), soft	16.2	89.8	-457.8	-454.5	-3.3	-3.98	-0.0206
		16.4	81.8	-388.1	-393.1	5.0		
		16.6	72.5	-327.7	-325.6	-2.1		
		16.8	60.7	-245.2	-245.1	-0.1		
		16.9	51.6	-187.3	-187.8	0.0		
10	Original condition, soft	19.4	86.4	-478	-472	-1	-5.51	-0.0145
		19.3	73.6	-372	-373	0		
		19.1	56.1	-243	-244	1		
		18.8	43.8	-160	-160	0		
		18.7	35.0	-103	-102	-1		
	Suddenly cooled (II), hard...	23.4	57.8	-235.3	-234.8	-0.5	-5.95	-0.0160
		23.4	50.9	-185.0	-185.6	0.6		
		23.5	47.1	-157.8	-153.3	0.5		
		23.7	42.6	-126.5	-126.0	-0.5		
		23.8	37.4	-92.8	-89.9	0.1		

TABLE 79.—*Thermo-electric power of cast iron. American material—Continued.*

Rod.	Remarks.	t	T	e observed.	e calculated.	Diff.	a	b
		$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	microvolt.	microvolt.			
10	Annealed at red heat (I), soft.	20.1	86.2	-382.8	-386.2	2.4	-4.12	-0.0163
		20.0	78.3	-338.1	-333.0	-2.1		
		19.1	69.2	-275.7	-274.2	-1.5		
		19.7	59.6	-214.5	-215.6	1.1		
		19.6	50.1	-160.0	-160.0	0.0		
11	Original condition, soft.....	21.6	74.9	-364	-364	0	-5.59	-0.0129
		21.6	67.4	-309	-308	-1		
		21.5	60.3	-258	-258	0		
		21.4	51.4	-196	-196	0		
		21.4	43.3	-141	-141	0		
	Suddenly cooled (II), hard..	25.8	57.6	-234.8	-234.6	-0.2	-6.96	-0.0054
		25.7	50.5	-181.1	-182.0	0.9		
		25.6	43.3	-151.7	-151.4	-0.3		
		25.6	42.6	-124.7	-124.1	-0.6		
		25.5	36.8	-81.8	-82.1	0.3		
	Annealed at red heat (I), soft.	19.0	80.6	-388.1	-389.9	1.8	-3.83	-0.0156
		19.0	80.3	-331.1	-329.6	-1.5		
		18.8	67.8	-254.3	-253.8	-0.5		
		18.7	60.6	-211.8	-212.2	0.4		
		18.5	51.6	-162.6	-162.9	0.3		
12	Original condition, soft.....	22.5	86.2	-449	-449	0	-5.58	-0.0139
		22.5	75.9	-369	-368	-1		
		22.6	68.9	-279	-279	0		
		22.4	51.6	-190	-192	2		
		22.4	40.7	-118	-117	-1		
	Suddenly cooled (II), hard..	12.1	57.9	-312.7	-311.0	-1.7	-5.88	-0.0137
		12.5	50.0	-249.5	-250.8	1.3		
		12.7	44.5	-208.9	-210.3	1.4		
		13.1	38.2	-164.3	-164.0	-0.3		
		13.2	34.3	-137.3	-136.7	-0.6		
	Annealed at red heat (I), soft.	19.5	97.9	-399.4	-399.9	0.5	-4.34	-0.0141
		19.5	80.2	-348.3	-348.3	0.0		
		19.4	67.3	-267.8	-266.1	-1.7		
		19.4	54.1	-184.5	-186.3	1.8		
		19.3	45.9	-140.4	-139.8	-0.6		

Resistance.—We give in the following table (80) the results for the electrical resistance of cast-iron. The rods are respectively identical to those for which the Tables 78 and 79 apply. Under W are contained the resistances per meter of length at the temperature t , in ohms; under q the two sides of the rectangular section of the rods, in centimeters; s_t and s_0 are the specific resistances at t° and 0° , the reduction having been effected by aid of the constant α , determined elsewhere.¹⁶² The rods are tested in the three states: original or commercial; after sudden cooling from red heat (II); after annealing at red heat (I).

¹⁶² Cf. Chapter I, p. 22.

TABLE 80.—*Electrical resistance of cast-iron.*

GERMAN IRON.

Rod.	Condition.	$W \text{ lm}$	t	q	$\frac{\text{cm}}{s \cdot \text{cm}^2 \cdot ^\circ\text{C}}$	a	$\frac{\text{cm}}{s \cdot \text{cm}^2 \cdot ^\circ\text{C}}$
		ohm.	°C.	$\frac{\text{cm}^3}{\text{cm}^2 \cdot \text{cm}}$	microhm.		microhm.
1 {	Original state	0.01235	16.0	0.771 · 0.771	73.4	0.0013	71.9
	Suddenly cooled (II)	1537	11.2	0.771 · 0.771	91.4	12	90.2
	Thoroughly annealed (I)	1070	14.5	0.758 · 0.758	61.5	13	60.4
2 {	Original state	0.0729	15.5	0.309 · 0.309	69.8	0.0013	68.4
	Suddenly cooled (II)	791	10.6	0.309 · 0.309	75.8	13	74.8
	Thoroughly annealed (I)	674	14.5	0.297 · 0.297	59.5	13	58.4
3 {	Original state	0.0750	15.5	0.307 · 0.307	70.6	0.0013	69.3
	Suddenly cooled (II)	790	11.4	0.307 · 0.307	74.4	13	73.3
	Thoroughly annealed (I)	683	14.5	0.293 · 0.293	58.8	13	57.7

AMERICAN IRON.

4 {	Original state	0.00981	23	0.977 · 0.936	89.7	0.0012	87.3
	Suddenly cooled (II)	1200	29	0.977 · 0.936	109.7	12	106.0
	Thoroughly annealed (I)	0848	16	0.977 · 0.936	77.5	12	76.1
5 {	Original state	0.00991	25	0.959 · 0.957	91.0	0.0012	88.8
	Suddenly cooled (II)	1244	25	0.959 · 0.957	114.2	12	110.9
	Thoroughly annealed (I)	0872	16	0.959 · 0.957	80.0	12	78.5
6 {	Original state	0.00981	25	0.951 · 0.950	84.1	0.0012	81.6
	Suddenly cooled (II)	1025	29	0.951 · 0.950	92.6	12	89.5
	Thoroughly annealed (I)	0677	16	0.951 · 0.950	79.3	12	77.8
7 {	Original state	0.01377	23	0.813 · 0.808	89.9	12	87.5
	Suddenly cooled (II)	1720	25	0.813 · 0.803	112.3	12	109.0
	Thoroughly annealed (I)	1214	16	0.813 · 0.803	79.2	12	77.7
8 {	Original state	0.01352	25	0.807 · 0.805	87.8	0.0012	85.3
	Suddenly cooled (II)	1561	29	0.807 · 0.805	101.4	12	98.0
	Thoroughly annealed (I)	1267	20	0.807 · 0.805	82.3	12	80.4
9 {	Original state	0.01403	25	0.790 · 0.789	87.4	0.0012	84.9
	Suddenly cooled (II)	1720	18	0.790 · 0.789	107.2	12	104.9
	Thoroughly annealed (I)	1265	16	0.790 · 0.789	78.9	12	77.4
11 {	Original state	0.02072	23	0.656 · 0.640	87.0	0.0012	84.7
	Suddenly cooled (II)	2510	25	0.656 · 0.640	105.4	12	102.3
	Thoroughly annealed (I)	1950	20	0.656 · 0.640	81.9	12	80.0
11 {	Original state	0.02173	25	0.643 · 0.642	88.7	0.0012	87.1
	Suddenly cooled (II)	2682	18	0.643 · 0.642	109.9	12	107.5
	Thoroughly annealed (I)	2075	20	0.643 · 0.642	85.7	12	83.7
12 {	Original state	0.02173	25	0.647 · 0.646	90.8	0.0012	88.2
	Suddenly cooled (II)	2624	25	0.647 · 0.646	109.7	12	106.5
	Thoroughly annealed (I)	2060	20	0.647 · 0.646	86.1	12	84.1

Digest.—In the following table the important results in Tables 78, 79 and 80, above, are systematically arranged for convenience in reference. It will be at once intelligible. We need only remark that in case of No. 1 the measurement of a was no longer possible for the soft annealed (I) condition, the rod having been accidentally broken. For this reason the value of a for the original state is taken for a_1 in the formation of Δa , and Δh . This, however, is quite permissible since the rod was originally soft. It may be added that in the tables the logarithms are primarily deduced, the antilogarithms from these. This table furnishes us with mean values for cast-iron. They are given in the final horizontal row.

TABLE 81.—*Electrical constants of cast-iron.*

Rod.	Thermoel. constant α , referred to soft silver, for $\frac{1}{2}(T+t)=0$ (in microvolt).			Thermoel. hardness, deduced from α and $\Delta=15.18-\alpha$, for $\frac{1}{2}(T+t)=0$ (in microvolts).						Specific electrical resistance $\rho_{\frac{1}{2}(T+t)=0}$ (in microhms).					
	α_1	α_2	$\Delta\alpha$	h_1	h_2	Δh	$\log h_1$	$\log h_2$	$10^4 \Delta \log h$	s_1	s_2	Δs	$\log s_1$	$\log s_2$	$10^4 \Delta \log s$
No. 1	(-4.94)	-7.04	2.10	(20.12)	22.22	2.10	1.3036	1.3457		43.160.4	90.228.8	1.7809	1.9551		174
No. 2	-6.84	-8.30	1.46	22.02	23.48	1.46	1.3423	1.3707		37.958.4	74.816.4	.7665	.8786		107
No. 3	-6.61	-8.12	1.51	21.79	23.30	1.51	.8389	.8674		29.157.7	73.815.6	.7610	.8561		104
No. 4	-4.43	-6.42	2.00	19.60	21.60	2.00	.2922	.3245		42.276.1	100.029.9	.8812	.9255		144
No. 5	-4.21	-6.78	2.57	19.39	21.96	2.57	.2876	.3416		54.078.5	110.932.4	.8949	.9448		159
No. 6	-4.27	-5.17	0.90	19.45	20.35	0.90	.2889	.3088		19.777.8	89.511.7	.8907	.9517		61
No. 7	-4.59	-6.39	1.80	19.50	21.47	1.97	.2900	.3318		41.877.7	103.081.9	.8906	.9375		147
No. 8	-4.08	-5.60	1.52	19.21	20.78	1.57	.2835	.3176		34.180.4	98.017.6	.9059	.9911		86
No. 9	-3.98	-5.64	2.66	19.16	21.73	2.56	.2824	.3369		54.577.4	104.927.5	.8885	.9299		123
No. 10	-4.12	-5.95	1.83	19.30	21.13	1.83	.2856	.3249		39.380.0	102.822.3	.9029	.9100		107
No. 11	-3.83	-5.98	2.15	19.01	22.11	3.10	.2790	.3446		65.683.7	107.528.8	.9225	.9316		109
No. 12	-4.84	-5.68	1.49	19.52	21.01	1.49	.2805	.3224		31.984.1	106.522.4	.9246	.9273		108
Means	-4.66	-6.58	1.92	19.84	21.76	1.92	.....	.....		40.874.4	97.828.4	.....	.....		119

DISCUSSION.

Plane diagram.—The experimental material in hand is sufficient for the discernment of the main and characteristic features of the relation which exists between the mechanical and chemical properties of iron-carburets, and their electrical behavior. We will arrive at our end soonest by proceeding graphically, using as the basis for our construction the general mean values given in Tables 76-77 and at the end of Table 81. As regards the interpretation of these data we derive very valuable clews from our earlier researches on the electrical properties of alloys. If to a given metal small amounts of a second metal be alloyed, the electrical constants are found to vary in a uniformly continuous way. Now, the total carbon in steel amounts to only 1-2 per cent; in cast iron to less than 5 per cent. We may therefore predict a mode of variation of specific resistances and thermo-electric power which shall be analogous to that observed for alloys. In other words, a uniformly continuous change in the electrical qualities of iron-carburets with the amount of carbon contained may justifiably be assumed. With the ultimate object in view of developing our diagram, let the percentage of total carbon, therefore, be represented as abscissa, the electrical constants h and s as ordinate. Carbon, however, occurs differently in iron-carburets when in the condition *I* than when in the other extreme condition, *II*. It is therefore necessary sharply to distinguish between the constants h_1 and s_1 belonging to the first or thoroughly annealed state, and the constants h_2 and s_2 for the hard state. Our data therefore furnish points belonging to two essentially different loci. Unfortunately for each of these, only three such points are in hand: the first

corresponding to wrought-iron and the abscissa, $x=0$; the second to steel where, approximately, $x=1.5$; the third to cast-iron, where we may roughly put $x=5.0$. The mean values of ordinate belonging to these abscissæ may be taken from the following little table:

TABLE 82.—Mean electrical constants of iron-carburets.

Material.	x	h_1	h_2	Δh	$10^8 \times \Delta \log h$	s_1	s_2	Δs	$10^8 \times \Delta \log s$
Wrought iron	0	4.7	4.7	zero	zero	12.2	12.2	zero	zero
Steel	1.5	6.0	17.8	11.8	460	15.0	41.2	26.2	440
Cast iron	5.0	19.8	21.8	1.9	40	74.4	97.8	23.4	120

With these data and the qualitative results just referred to, our attention will be first directed to the hard state, *II*, of iron-carburets. Between $x=0$ (iron), and $x=1.5$ (steel), iron-carburets vary in marked degree as regards hardness, a circumstance observable both in the mechanical and electrical properties (h_2, s_2) of these products. Beyond this, approaching castiron, the variations are slight. The curve rises rapidly at first, finally at a gradually decreasing rate, and is therefore as a whole concave towards the axis of abscissæ.

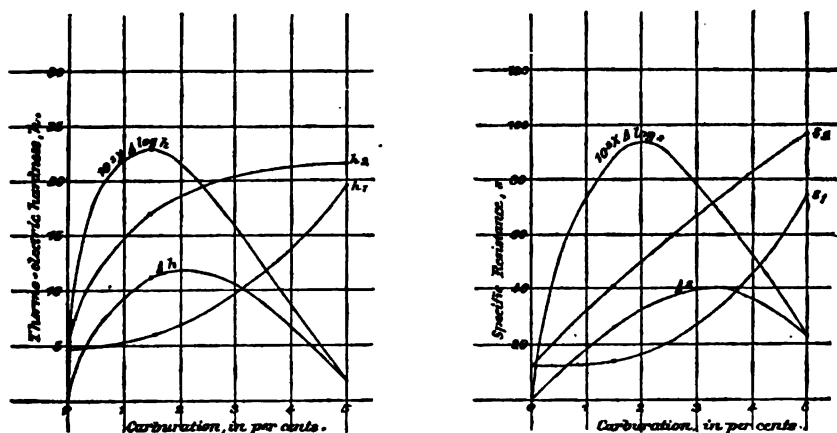


FIG. 24.—Diagram of the mean variation of the thermo-electric hardness and the specific electric resistance of iron-carburets, with their degrees of carburation; 1, thoroughly annealed state; 2, suddenly cooled state.

A result almost the inverse of this is encountered in the case of the "soft" state *I*. Here the initial variations are insignificant, soft iron and soft steel differing slightly, not only in their mechanical states of hardness, but also in the electrical manifestation (h_1, s_1) of this quality. It is not until we pass beyond $x=1.5$ and enter the region of the cast-irons that the present curve *I* rises at a relatively rapid or accelerated rate. The curves, *I*, are therefore on the whole convex as regards the axis of abscissæ.

From these points of view the curves in the above diagram h_2, s_2

and h_1, s_1 have been drawn. It may be plainly argued, moreover, that their general character does not change during the progress from $x=0$ to $x=5$; in other words, we accept concavity and convexity respectively throughout the given extent of the curves, to the exclusion of points of circumflexion. With this probable inference postulated, we observe that the two sets of curves h_2, s_2 and h_1, s_1 must intersect in the region of cast-iron, that is, near $x=5$.

Curiously enough we found in certain data of Joule¹⁶³ the evidence for such intersection. If we reduce Joule's figures to our scale of thermo-electric hardness, his results for white cast-iron and gray cast-iron are approximately these:

First extreme: cast-iron, black fracture (with much graphite), $h=25$.

Second extreme: cast-iron, white fracture (very hard), $h=12$. All other samples of cast-iron which he examined lay between these limits. The large values for h and s obtained¹⁶⁴ for malleable cast-iron (known to be graphitic¹⁶⁵) are also in accordance with Joule's results. The first mentioned of the cast-irons above ($h=25$) is therefore to be referred to condition *I* (soft, carbon uncombined), the second ($h=12$, carbon combined, hard) to condition *II*, which gives evidence in favor of the intersection of the respective curves.

Superimposed electrical effects.—To this inversion of the electrical properties of iron-carburets as the quantity of total carbon is increased we have already adverted,¹⁶⁶ and it is therefore essential to any discussion of the phenomena before us to take cognizance of the mechanical as well as the chemical causes of the same. These are three in number: (1) Effect of uncombined carbon; (2) effect of combined carbon; (3) effect of the peculiar strain accompanying temper.

In the curves h_1 and s_1 the first of these factors is primarily active, the second of small importance, the third inactive. The material is approximately homogeneous. In the curves h_2 and s_2 , however, all factors produce their own specific results, though the influence of the first is relatively small. Here, therefore, we are confronted by a complex superposition of effects; such however, that between wrought-iron and steel the mechanical cause (3) is almost solely efficient; between steel and cast-iron the chemical causes (1, 2) predominate.

Character of Δh .—As the result of the opposed character of the curvatures of the loci *I* (soft state) and *II* (hard state), the first being convex, the second concave, as regards the axis of abscissæ, we are able to draw an inference of fundamental importance. For if we put $\Delta h = h_2 - h_1$ and $\Delta s = s_2 - s_1$, then it follows obviously that the new variables Δh and Δs , regarded as functions of x , must each pass through a maximum. This remarkable result may be formulated thus:

The diagram which expresses the electrical behavior of commercial

¹⁶³ Joule: l. c.

¹⁶⁴ Chapter III, p. 102.

¹⁶⁵ Forquignon: l. c.

¹⁶⁶ Chapter III, p. 103.

iron-carburets distinctly indicates the existence of a singular product, possessing the unique capability of occurrence in the greatest number possible of mechanical states—a member, in other words, for which the difference of thermo-electric hardness between condition *II* and condition *I* is a *maximum*. This is a necessary but not a sufficient condition for the definition of that valuable product to which the term “steel” is applicable. For, irrespective of the fact that $\Delta h = \max.$ and $\Delta s = \max.$ need not necessarily select the same product, a definition based solely on the absolute value of the interval of variation does not necessarily exclude the occurrence of any marked change of hardness as regards the soft state. Yet this is essential. The mere fact, in other words, that for the unique iron-carburet in question the state *II* is furthest removed with reference to hardness from the state *I*, might even be true of a product brittle in the latter (soft) state.

Character of $\Delta \log h$.—To meet this objectionable feature of the above definition, therefore, it is expedient to give preference not to the absolute variations of h and s , but to the relative variations $h_2 : h_1, s_2 : s_1$, of pairs of values of h and s . For this reason the *logarithmic* interval is considered. If $\Delta h = \log h_2 - \log h_1$ and $\Delta s = \log s_2 - \log s_1$, then we have for the definition of steel $\Delta \log h = \max.$, or $\Delta \log s = \max.$ Between these we have yet to decide. In the first place it is to be noted that the equations $\Delta h = \max.$ and $\Delta s = \max.$, determine $x=2$ and $x=3$, respectively, and so far as can as yet be foreseen; whereas $\Delta \log h = \max.$ and $\Delta \log s = \max.$, apply for $x=1.5$ and $x=2.0$, respectively. In the latter case, therefore, not only are the two carburets defined chemically much more nearly coincident, but their mean position in the diagram is such as to select from all the iron-carburets the one which may stand as a *type* for the products commercially termed steel. And we may add here that, in so far as the variation of a function like the one in hand in the neighborhood of a maximum is usually small, a group of iron carburets disposed on either side of the said maximum will possess properties sufficiently alike to enable us to consider them as practically and commercially identical with the accurately defined type. Now it is very probable, if material of sufficient purity could be obtained, that both the equations $\Delta \log h = \max.$ and $\Delta \log s = \max.$ will be found satisfiable by the same x , and this from the fact that as far as steel, at least, the relation between thermo-electric hardness and specific resistance is linear. But after subjecting any iron-carburet to the process of sudden cooling, the external layers will usually have been transferred into the state *II* more thoroughly than the core, particularly in case of thick rods and highly carburized iron. But it is from the external layers that $\Delta \log h$ is practically determinable, irrespective of the figure and dimensions of the carburet operated upon. $\Delta \log s$ is not readily determinable except for the mean condition of a carburet of definite figure.

Definition of steel.—Preference is, therefore, to be given to the former of the two critical equations and $\Delta \log h = \text{maximum}$ to be accepted as the physical definition of steel. This equation is to be interpreted thus:

Let each member of the whole series of non-carburets be subjected successively to the following two operations:

1. A process of very slow cooling from a given temperature in red heat.
2. A process of most rapid cooling possible from the same temperature.

If now the carburets be examined with reference to the hardness produced in the two instances, there will be found among them a certain unique member whose properties are such that while process *I* has more nearly identified it with pure soft iron; process *II* will have moved it farther away from this initial carburet¹⁶⁷ than is simultaneously the case with any other iron-carbon product; or which, in other words, is capable of occurring in the greatest number of states of hardness *relative to the soft state* possible. To this unique product the term “steel” is to be applied.

In so far, however, as the softest steel, for the very reason of its being essentially an iron-carburet, can never reach pure iron, it is obvious that there must remain a *difference* between the mechanical properties (Young's modulus, simple rigidity, tenacity, etc.) in general of soft iron and soft steel, on account of which preference will be given to one material or the other, as the needs of the engineer suggest. To this carburet ($\Delta \log h = \text{max.}$), finally, the maximum capacity for the retention of a strain of any given kind which may be imparted to it, seems also to belong. The strain accompanying magnetism, and the strain peculiar to hardness, of each of which steel retains a phenomenal amount, may be cited as examples.

COMMERCIAL OR IMPURE IRON-CARBURETS.

Series of iron-carburets.—Thus far no attention has been paid to the unavoidable impurities like sulphur, silicon, phosphorus, manganese, etc., which in addition to carbon are always present in commercial iron-carbon products. But it is easy to extend the considerations just made in such a way as will make them applicable to iron-carburets, pure and impure, generally. Let any iron-carburet be given. To this belong a whole series of iron-carburets so constituted that, while in other respects the composition is identical throughout, carbon alone passes through the interval from zero to about six per cent.¹⁶⁸ To each such series (see

¹⁶⁷ That is, soft iron for which $x=0$.

¹⁶⁸ Of course, the increment in C in this case presupposes a decrement in total Fe, so that there may be no variation in the percentage presence of the impurities.

below, p. 191) a definite and characteristic pair of curves, h_2 and h_1 , will correspond, and that particular impure iron-carburet which is selected by the equation

$$\Delta \log h = \text{maximum}$$

is the steel for the given class of impure iron-carbon products. These relations may be tersely exhibited as follows. Let

$$z_1 = f_1(a, b, c \dots x)$$

where z_1 denotes the thermo-electric hardness of a given sample of impure iron-carburet, $a, b, c \dots$, are parameters expressing the respective amounts of the impurities present in per cents. by weight of the whole, x (independent variable) representing the total carbon present, also in per cents. of the whole.

Let

$$z_2 = f_2(a, b, c, \dots x)$$

be interpreted in like manner. Now suppose the functions z_1 and z_2 to belong simultaneously to the same product, or in other words, to apply when the said given product is in the state *I* and the state *II*, respectively.¹⁶⁹ Then will these equations, if x be allowed to increase continuously from zero to about six, express the critical electrical properties of the whole given series of impure iron-carburets. Again by varying any one or all of the parameters, $a, b, c \dots$, we may pass from a given series of this kind to any other.¹⁷⁰ Finally the function, in the case of a given series,

$$\Delta \log z = \log z_2 - \log z_1$$

possesses the important property that for wrought iron its value approaches zero; for cast-iron its value is some positive number, and for steel we shall have $\Delta \log z = \text{maximum}$. In order to determine the position of any iron-carburet in its own series a knowledge of the functions z_1 and z_2 is fully sufficient.

Thermo-electric hardness—general interpretation.—With these new inferences we are able to give the results of an earlier chapter (II), a much more comprehensive interpretation. The extreme values of thermo-electric hardness, z_1 and z_2 , corresponding to thorough annealing and sudden cooling, respectively, describe any given member of any given series of iron-carburets with reference to its chemical properties; i. e., z_1 and z_2 , together, determine its position in a diagram of classification peculiar to iron-carburets. The intermediate values of z , in other words, those lying between z_1 and z_2 , and obtainable by the annealing of the previously chilled carburet, describe the same product with reference to its mechanical properties; i. e., the value of z deter-

¹⁶⁹In practice f_1 and f_2 will be interpolatory functions of like character.

¹⁷⁰It is to be borne in mind here that these remarks apply principally for iron-carburets, in which x does not exceed 2. The final generalization is given below.

mines its position in a scale of hardness peculiar to the particular iron-carburet (z_1, z_2) in hand.

Herewith we have succeeded in expressing the general conception of a problem, of which our research on the hardness of steel (Chapter II) is to be regarded as only a special solution.¹⁷¹

FINAL GENERALIZATION.

Qualitative and quantitative carburization.—In the above discussion the general features of the electrical behavior of iron carburets, whose degree of carburization is above 2 per cent., has already been given. But a more detailed consideration must take cognizance of the fact that even in case of the same chemical composition we encounter iron-carburets differing enormously in their physical properties, and we are led into a host of complications not readily to be surveyed. The mode of occurrence of carbon in iron, or what may be called the quality of carburization, becomes more and more dominant in effecting changes of physical character of these products, as the amount of total carbon present is increased. The temperature in red heat from which the conditions *I* (thoroughly annealed) and *II* (suddenly cooled) are reached, as well as the time during which exposure to the same takes place, here possesses essential importance.

Classification-function.—The prolongation of the critical curves h_1 and h_2 from steel into the region of cast-iron can therefore be made in a great variety of ways. For each particular path definite premises must be laid down, viz., that the increase of carbon shall take place, qualitatively as well as quantitatively, in a way such as is in accordance with the manner of carburization of the sample of cast-iron, in which the particular path in question is to terminate. Perhaps these relations are expressible with greater clearness in this wise: Suppose that with reference to the height and duration of the temperature from which thorough annealing (*I*) and sudden cooling (*II*) is to be effected, etc., certain fixed assumptions have been made. But beyond this let it be unrestricted, so that it may even lie beyond the melting point of the carburets operated upon. Furthermore, suppose the percentage amount (parameter) of foreign admixtures and impurities other than carbon present in iron be constant throughout. Then let the relations here involved be represented graphically in three dimensions: Thermo-electric hardness parallel to the axis Z ; carburization quantitatively considered (percentage

¹⁷¹A good example of the difference between mechanical and thermo-electric hardness is given by malleable cast-iron, results for which are given elsewhere (Chapter III, p. 102).

of total carbon) parallel to the axis X ; finally qualitative carburation,¹⁷² i. e., a quantity which expresses the mode of occurrence of carbon in iron, parallel to the axis Y . With this understanding a characteristic surface will correspond both to condition *I* and condition *II*; and if analogously to the above (p. 189), we deduce the difference $\Delta \log z$, its form will be

$$\Delta \log z = F(a, b, c, \dots y, x)$$

where the parameters $a, b, c, \dots$ refer to the impurities present.

Every plane parallel to XZ cuts this surface in a curve, expressing the electrical behavior of a series of iron carburets as above defined (p. 188). All such curves of intersection are characterized by the presence of a maximum defining the steel corresponding to the impure iron, $F(a, b, c, \dots y, 0)$, the initial carburet of the particular series under consideration.

Every plane parallel to YZ cuts the surface $\Delta \log z$ in a curve, expressing the electrical behavior of all carburets possible in case of a selected fixed amount of total carbon in the iron carburet. Two such curves will differ more as their distance apart as well as from the initial plane YZ is greater. It will be seen that the further step in the present research must be that of suitably varying the elements of the operations *I* and *II*¹⁷³ in such a way as to throw additional light on all these complications, among which those last mentioned are as yet the most obscure and imperfectly understood.

Classification diagram.—Notwithstanding the dangers encountered in representing views in part theoretical with the aid of a diagram, we are able to bring to the mind of the reader all that has been said so perspicuously in this way, as readily vindicates the venture of a rough construction of the probable contour of the surface $\Delta \log z$. In the following figure (25) the XZ plane cuts the surface $\Delta \log z$ (*rstno*) in a line coinciding with the axis X . This is supposed to be an hypothetical carburet, iron-graphite, which remains iron-graphite both in state *I* and in state *II*. The extreme plane parallel to XZ represents the series of

¹⁷² As an example of the nature of the variable y , suppose it, for instance, to be the mean ratio of combined to uncombined carbon for the two states, *I* and *II*, or, $y = \frac{1}{2} \left\{ \left(\frac{\text{combined } C}{\text{uncombined } C} \right)_I + \left(\frac{\text{combined } C}{\text{uncombined } C} \right)_{II} \right\}$. Should a single quantity, y , be insufficient to express the qualitative occurrence of carbon, so that a number of such variables $y, y', y'', \dots$ are necessary, then while any given one, y for instance, passes all values, the others are to be regarded as parameters—i. e., constants during this variation. The presence of graphite, amorphous carbon, and combined carbon in iron may suggest two variables, y, y' .

¹⁷³ Much, for instance, could be learned from continuous electrical ignition of iron-carburets, in vacuo and gases, respectively, and examination of the test sample from time to time; more from a detailed exploration of these phenomena, made conjointly by a physicist and a chemist. Carburization produced by ignition in gaseous hydrocarbons, and subsequently in vacuo, suggests itself as a first convenient method of experimental attack.

iron-carburets (*rst*) in which all carbon is combined, at least in state *II*. White cast-iron may be supposed to belong to this series. The plane

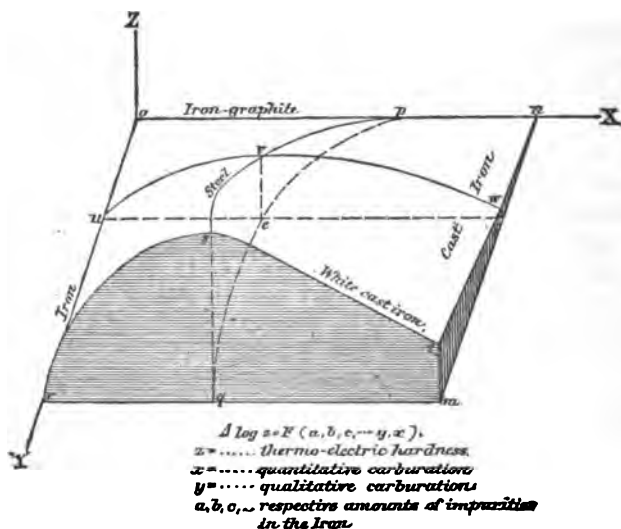


FIG. 25.—Classification diagram.

YZ intersects the surface $\Delta \log z$ in the iron line approximately coinciding with the axis *Y*. The extreme plane (*mtn*) parallel to *YZ* corresponds to about $x=6$. The most interesting feature of the diagram is the totality of steel maxima (*svp*). If ordinates be let fall from each of these, the resulting cylinder will intersect the plane *XY* in a curve (*peq*), expressing both qualitatively and quantitatively the carburization of the infinite steels possible in case of a given impure iron-carburet $F(a, b, c, \dots y, x)$. It is hardly necessary to add that the number of such possible surfaces (*rstno*) is again infinite; since any variation of the parameters $a, b, c, \dots$ or the accessory variables $y, y', y'', \dots$ involves the construction of a new one. Practically, however, a finite number of typical surfaces suffice.

The figure finally contains an illustrative intermediate section, in which *v* is the steel of the series of iron-carburets *uvw*.

Concluding remarks.—The perusal of the above pages will have shown that the problem in hand, considered in its full generality, is exceedingly complicated. Nevertheless, we presume to believe that the method of attack which has been briefly developed in this chapter contains promise of success. Both the intimate relationship between the mechanical properties of iron-carburets and their electrical behavior, as well as the incomparable sensitiveness of the functions involved, emphatically commend our electrical diagram to the metallurgical engineer. Indeed, it is remarkable that metallurgists have thus far given no attention to a class of physical properties which, from their simplicity

and pronounced character, seem above all others to be adapted for purposes of discrimination and classification. Magnetic functions, as we have shown elsewhere, admit much less readily of satisfactory interpretation, varying as they do enormously with the figure and dimensions of the sample under examination. The interest of the present chapter, however, centers in the important product, steel. Curiously enough, the large range of variation of mechanical properties which renders this substance so indispensably useful have not as yet been found available for its accurate definition. The electrical qualities of steel, however, furnish a means to this end, which can conveniently be pushed to greater detail and nicety than will be necessary for any metallurgical or even physical purposes. It is in this respect that we believe with the present publication to have opened a new field of research, useful alike in its bearing on the practical and the theoretical problems concerning iron-carburets.

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CHAPTER VIII.

BRIEF SUMMARY OF THE PRINCIPAL DATA.

Introduction.—The remarks in this memoir refer almost exclusively to the species of hardness known as temper, and which may be imparted to iron-carburets by sudden cooling from red heat combined with more or less subsequent annealing.

It falls within the scope of the work to develop so far as possible the very close analogy which exists between tempering and magnetization.

If we define the structure of a hard cylindrical steel rod as being the law of variation of density encountered on a passage from axis to circumference along any radius of the rod, then structural identity in case of two given geometrically similar rods of the same composition *a priori* implies identity of diameter. In what way structure may vary with diameter is not even conjecturable. It follows that immediately comparable magnetic data are to be anticipated only where the rods of variable hardness and length retain the same thickness and composition throughout the course of the experiments.

Chapter I.—Like the specific resistance, the galvanic temperature-coefficient of the iron-carburets exhibits a phenomenal range of variation, passing from the values for wrought iron and soft steel, 0.0052 and 0.0043, respectively, to the values for hard steel and cast iron, 0.0016 and 0.0013, respectively. The said coefficient decreases continuously and uniformly as resistance increases, more rapidly than the latter during the earlier stages, much more slowly during the later stages of a progress from iron to cast iron. An inferior limit of the temperature-coefficient would therefore seem to appear much before the iron-carburet reaches the superior limit of resistance. If classified with reference to the relation between resistance and temperature, the iron-carburets as a whole form one continuous series.

Chapter II.—If the temperature from which steel is suddenly cooled be supposed to increase continuously from a very low value to the highest admissible, the hardness of the chilled rod will remain comparatively inappreciable until a certain critical temperature in red heat is reached. At this stage and a little beyond hardness increases at exceedingly rapid rates with temperature, after which the rate again decreases.

The largest observed variation of thermo-electric power produced by

tempering is 12.8 microvolts per degree centigrade at 0° . The largest ratio of the respective resistances of hard and soft steel

$$45 \text{ (cm / cm}^2, 0^{\circ}, \text{ microhm)} : 15 \text{ (cm / cm}^2, 0^{\circ}, \text{ microhm)} = 3.$$

Since hard and soft steel lie on opposite sides of pure silver in the thermo-electric scale, maxima and neutral points of electromotive force (thermo-electric inversions) are a common occurrence.

The annealing effect of any temperature acting on glass-hard steel increases gradually at a rate diminishing continuously through infinite time—diminishing very slowly in case of low temperatures ($< 100^{\circ}$), very rapidly at first, then again slowly in the case of high temperatures ($> 200^{\circ}$); so that the highest and hardest of the inferior states of hardness possible at any given temperature is approached asymptotically.

The ultimate annealing effect of any temperature t° is independent of the possibly pre-existing effects of a temperature t'° , and is not in any way influenced by subsequent application of the latter, provided $t > t'$. In case of partial annealing at t° (time finite) this law applies more fully the more nearly the said ultimate effect of t° is reached.

If hardness of steel is to be expressed thermo-electrically, it is inexpedient to use the soft state as a point of departure. The thermo-electric difference between soft steel and soft iron (say 1) when compared with the corresponding difference between the extreme states of steel (say 10) is small. In soft steel, however, the effect of foreign ingredients (impurities: S, P, Si, Mn, etc.) is still too pronounced to admit of a desirably accurate determination of the thermo-electric position¹⁷⁴ of this metal.

In the case of steel, the relation between thermo-electromotive force per degree centigrade at 0° , and specific resistance at 0° (s), is linear throughout the whole of the phenomenal range of variation of these qualities with hardness. This law suggests the introduction of the new variable *thermo-electric hardness* (h), defined thus: Suppose the said law of linear variation to be true indefinitely; then will the electromotive force (microvolt) per degree centigrade at 0° of a thermo-element consisting of steel in the imaginary normal state whose specific resistance (cm / cm² 0° microhm) is zero, and steel in any given state, be the thermo-electric hardness of the latter. The thermo-electric position of steel in the stated normal condition, with reference to pure soft silver, is

$$m = 15.18 \text{ microvolts}$$

per degree C. at 0° . Finally in the fundamental equation $h = ns$,

$$n = 0.412$$

Chapter III.—The chemical theory of the phenomenon of temper leads to this ulterior inference. By the simple process of sudden cool-

¹⁷⁴It may be added here that, even if chemically pure steel were available, its thermo-electric position would, very probably, be seriously variable in consequence of unknowable differences in the mode of occurrence of the carbon contained.

ing, combined with subsequent annealing, applied to steel, inasmuch as in this way, within certain limits, any given amount of an electrically active ingredient (carbon) may be converted into an electrically passive form, the same results are reached which in the case of alloys are obtainable only by melting the two component metals together.

In the case of alloys, the plane locus determined by thermo-electric power (microvolts) per degree centigrade, at 0° , and specific resistance ($\text{cm} / \text{cm}^2 0^\circ \text{ microhm}$) shows maxima (or minima) for both properties, so disposed that the said singular points, at the temperature 0° at least, do not coincide. The range of variation of the electrical properties in question appears to increase with the difference of specific volume of the (two) ingredients of the alloy. Applied to steel, the results interpret the observed linear locus for the metal (steel) as being the initial tangent of a curve of comparatively enormous magnitude.

Variation of resistance is a necessary concomitant of variation of volume; no matter how the latter may have been produced—whether by temperature or by tempering—the increments of resistance (s) due to a given increment of volume (v) are of the same order. A purely thermal effect in the one case does not therefore appear. If we put

$$s_2 = s_1 \left(1 + k \frac{v_2 - v_1}{v_1} \right)$$

$$k = \frac{s_2 - s_1}{s_1} : \frac{v_2 - v_1}{v_1} = 150, \text{ a first approximation.}$$

Gentle ignition after a previous state of (hard) temper appears to be generally accompanied by a passage of both resistance and volume through minima.

The annealing effect of temperature and time in the case of drawn hardness is quite analogous to the said effect in the case of temper.

The position of cast iron is isolated with respect to the locus expressing the simultaneous variation of thermo-electric power and specific resistance due to changes of temper in case of the other carburets (steel). Cf. this résumé, Chapter I.

The chemical theory does not suggest nor account for the observed phenomena of annealing. Considered physically these are at once referable to the category of viscous phenomena. In the ordinary cases of viscosity measurement, the phenomenon is evoked by sudden application of stress (torsion, flexure, tension, volume compression or extension, etc.) under conditions of constant viscosity; in the case of annealing, by sudden decrease of viscosity under conditions of initially constant stress. Thermal expansion interferes with the purity of these phenomena by destroying the conditions of existence of the characteristic strain which accompanies hardness, and this in proportion as the expansion is greater. The final evidence in favor of the given interpretation (viscosity) of the phenomena of annealing is this: that the maximum of permanent hardness which can in any way be imparted to steel

(i. e., the maximum intensity of strain which a steel rod is of itself able to maintain) decreases rapidly as temperature increases. (Cf. Chap. III, p. 97.)

The temperature condition (cf. Chapter II of this résumé) to which the appearance of glass-hardness is subject, is readily suggested by the chemical theory. Physically the state of red heat of iron and of steel is remarkable for the occurrence of certain characteristic phenomena: sudden volume-expansion (Cumming); anomalous thermo-electric behavior (Tait); disappearance of the magnetic quality (Gore); sudden appearance of glass-hardness in steel chilled from this temperature (Chernoff). An anomalous variation of resistance may be additionally inferred. As regards conditions favorable to glass-hardness Cumming's phenomenon distinguishes iron and steel from all other substances. The difference between iron and steel, finally, is exhibited in like degree by the maximum of permanent magnetization, by the maximum of permanent hardness (Strain), and probably by the maxima of other strains which these metals, under like conditions, respectively retain.

In the substance malleable cast-iron there is encountered a remarkable example of the occurrence of mechanical hardness unaccompanied by an equivalent variation of the electrical properties.

The existence of the characteristic strain in glass-hard steel is the cause of electrical effects so enormous that such additional effects which any change in carburization may involve can be wholly disregarded, and all electrical and magnetic results interpreted as due solely to variations in the intensity of the said strain.

Chapter IV.—Both the galvanic and the thermo-electric effects of magnetization are negligible in comparison with the corresponding electrical effects of tempering—the former amounting to less than 0.3 per cent. of the latter in the most unfavorable case.

The absolute value of the said thermo-electric effect for magnetically saturated iron is $+0.035$ microvolts per degree centigrade, at zero.

The thermo-electric effects of a temporary tensile strain in iron and of magnetization are qualitatively alike. Hence we infer that the latter effect is to be attributed to the strain which accompanies magnetism.

Chapter V.—Rigidly comparable data of the relation between magnetism and hardness are not readily obtainable except with magnets which were originally integrant parts of the same (hard) steel rod of uniform temper throughout its length. The plan of experimentation is expediently made to conform with a passage from hard to soft.

If magnetic moment (C. G. S.) per unit of mass (g) be regarded as a function of hardness, the family of curves obtained exhibits the following general character: Magnets, whether long or short, after incipient annealing from the glass-hard state diminish in magnetizability to a pronounced minimum of this quality. If the annealing be continued magnetizability again increases to an enormously developed maximum in case of rods of large dimension-ratio, to a flat or indistinct maximum in case of small dimension-ratio. On passing from long to short steel rods

the minimum is found to move in a direction from hard to soft, at very slow rates, thus remaining in the region of glass-hardness; the maximum, on the other hand, in a direction from soft to hard, at somewhat more rapid rates. The unique maximum of permanent magnetizability will probably be exhibited by a linear steel rod, annealed from glass-hardness as far as the physical state of maximum density. The value of the unique maximum is demonstrably much above 785 C. G. S. units of intensity, or 100 C. G. S. units of moment per gramme-mass. Continued diminution of the dimension-ratio finally, will probably bring the said minima and maxima into coincidence in such a way that permanent magnetizability decreases uniformly from hard to soft.

The family of magnetic curves must be separately investigated for each given diameter (structure) and each given degree of carburization. If magnetic moment per unit of mass be regarded as a function of the dimension-ratio (α = length / diameter), the family of curves obtained (conveniently described with the aid of the four type curves: "glass-hard," "yellow annealed," "blue annealed," "soft,") exhibit the following general character:

The curve "glass-hard" is concave as regards the axis of abscissæ (dimension-ratio) throughout. Rising very rapidly at first, it finally ascends to a distinct limiting value or horizontal asymptote. The curve "soft," on the other hand, rises very slowly in its earlier stages, and is convex as regards the axis of abscissæ. From here it passes rapidly through a point of circumflexion into concavity, and then above the former curve. Finally, the rate of ascent again decreases, so that a horizontal asymptote is also reached, but apparently at a later stage of progress than is the case with hard steel.

From either of these two loci expressing the variations of the extreme states, we may by annealing pass continuously to the other. But the manner of such passage, from the one curve to the other, in consequence of the continuous change of parameter (hardness), is exceedingly complicated. Incipient annealing of glass-hard steel produces a distinct, though relatively small, descent of the original curve as a whole. As annealing progresses, the farther end of the curve is always the first to rise and to pass above the original curve in such a way that the point of intersection of the new curve and the original curve (glass-hard) moves along the latter with great rapidity, from greater to smaller values of the dimension-ratio. When the curve "yellow annealed" is reached, the part of it between a small value of the dimension-ratio, α (= 14 and 18, in the above measurements, for diameters $2\rho = 0.08$ cm. and 0.15 cm.), and $\alpha = \infty$, has been already elevated above the curve "glass-hard." At the stage of progress given by the blue annealed curve, the part between another small value of α ($\alpha = 15$ and 20 in the above results) and $\alpha = \infty$ has risen far more rapidly than before, while, on the other hand, the advancing part of curve between $\alpha = 0$ and the said small value ($\alpha = 15$ or 20, respectively) having descended very grad-

nally, is now distinctly convex downward. Passing from "blue annealed" to "soft," the part of the curve above smaller dimension-ratios continues to fall, in general at greater rates, finally to merge into the curve "soft." The remaining part, above greater dimension-ratios, still rises slowly, reaching its superior elevation, from which it then falls rapidly into coincidence with the extreme curve "soft" also. During this last phase of progress the point of intersection of the advancing curve and the curve glass-hard passes along the latter from smaller to larger values of the dimension-ratio.

Chapter VI.—In considering the permanent magnetic effect of temperature on steel permanently saturated, it is necessary to discriminate sharply between two species of magnetic loss:

1. The direct effect, due simply to the action of temperature, and to be ascribed to diminution of coercive force and to interference of thermal expansion with the magnetic strain.

2. The indirect effect, due to the action of temperature in producing mechanical annealing, and to be ascribed to the interference of the re-arrangement of molecules resulting, with the magnetic strain.

The two effects are frequently superimposed. Considered separately, the latter (indirect effect) is by far the greater in amount, and its character, with regard to magnitude and duration, fully typified by the concomitant phenomenon of ordinary mechanical annealing. The former (direct effect) is not only of smaller magnitude, but subsides completely within a very much smaller interval of time. A third (temporary) effect of temperature does not fall within the scope of the present work. If the contemporaneous effects of the action of temperature on permanently saturated glass-hard magnets, viz., reduction of magnetic moment per unit of mass (ordinates) and of specific resistance (abscissæ), be compared graphically, the loci of the relation pass from pronounced convexity, as regards the axis of abscissæ, almost horizontally through a point of circumflexion into pronounced concavity. It must be borne in mind that both the direct and indirect effects are here superimposed. The said curves, if constructed for different dimension-ratios, are approximately parallel, presenting greater curvature, however, for smaller dimension-ratios than for larger. The immediate bearing of temper on the indirect effect is strikingly shown by the fact that, in the case of long, hard, permanently saturated steel rods, the relation between permanent magnetism per unit of mass and resistance, where both variations are simultaneous and due to changes of temper only, and where the latter occurs between the maximum of permanent hardness for ordinary temperature and the maximum of the same quality for 100° , is ultimately ($\alpha = \infty$) linear.

The maximum of permanent magnetization for any given temperature, t° , which can be imparted to a steel rod exhibiting the maximum of permanent hardness for the same temperature, t° , is wholly independent of the possibly pre-existing states of magnetization. If $t = 100^{\circ}$,

such magnets possess exceptional retentiveness both as regards effects of (atmospheric) temperature and time and of percussion.

The following rules for the practical treatment of magnets, where great retentiveness is the principal desideratum, we believe to be justified in submitting:

1. Rods tempered glass-hard are not to be used as essential parts of magnetic instruments.

2. Having tempered a given steel rod in such a way as insures uniformity of glass-hardness throughout its length, expose it for a long time (say 20-30 hours; in case of massive magnets even longer intervals of exposure are preferable) to the annealing effect of steam (100°). The operation may be interrupted as often as desirable. The magnet will then exhibit the maximum of permanent hardness for 100° .

3. Magnetize the rod—whether originally a magnet or not is quite immaterial—to saturation, and then expose it again for about 5 hours (in case of massive magnets even larger intervals of exposure are preferable) to the annealing effect of steam (100°). The operation may be interrupted as often as desirable. The magnet will then exhibit both the maximum of permanent magnetization as well as the maximum of permanent hardness corresponding to 100° . Its degree of magnetic retentiveness against effects of temperature ($< 100^{\circ}$), time, and percussion is probably the highest conveniently attainable.

Chapter VII.—Given any iron-carburet, pure or impure.

Suppose carburation to vary continuously from 0 per cent. to 6 per cent. by weight of the whole, in any definite manner, and in such a way that increment in total carbon is compensated by decrement in total iron. Let there be no further change in the ingredients of the carburet. In this way we generate a special *series* of iron-carbides of which the given carburet is a particular member.

Such a series of iron-carburets exhibits the following characteristics:

If cooled from a temperature in red heat as rapidly as possible, thermo-electric hardness varies continuously with carburation, at a gradually retarded rate, and in such a way that the locus ascends rapidly during the earlier stages of progress, very slowly during the later stages. As a whole, therefore, the curve shows pronounced concavity downward.

If cooled from the same temperature in red heat with all desirable slowness, thermo-electric hardness varies continuously with carburation, at a gradually accelerated rate, and in such a way that the locus ascends slowly during the earlier stages of progress, very rapidly during the later. As a whole, therefore, the curve shows pronounced convexity downward.

The difference between the values of thermo-electric hardness for the same carburation passes through a maximum in the region of steel.

The difference between the logarithms of the respective values of thermo-electric hardness for the same carburation passes through a pro-

nounced maximum, defining a carbide, the mechanical properties of which are those of a type steel, and may be fully given thus:

Let each member of the whole series of iron-carburets be subjected successively to the following operations:

- I. A process of very slow cooling from a given temperature in red heat.
- II. A process of most rapid cooling possible from the same temperature.

If now the carburets be examined with reference to the hardness produced in the two instances, there will be found among them a certain unique member, whose properties are such that while process *I* has more nearly identified it with pure soft iron, process *II* will have moved it further away from this initial carburet than is simultaneously the case with any other iron-carbon product; a unique member, in other words, which is capable of occurring in the greatest number of states of hardness relative to the soft state, possible. To the said product the term "steel" is to be applied.

Similar deductions may be made from the critical values of specific resistance of iron-carburets.

The variation of a function like the one in hand in the neighborhood of a maximum is small. Hence a group of iron-carburets disposed on either side of the said maximum will possess properties sufficiently alike to be practically or commercially identical with the accurately defined type.

The general statement of the problem of which a special solution is contained in Chapter II is this:

The extreme values of thermo-electric hardness, *i. e.*, the values corresponding to sudden cooling and thorough annealing, respectively, describe any given member of any given series of iron-carburets with reference to its chemical properties. In other words, the said extreme values fix its position in a diagram of classification peculiar to iron-carburets. The intermediate values of thermo-electric hardness, *i. e.*, the values lying between the extremes and obtainable by annealing of the previously chilled carburet, describe the same product with reference to its mechanical properties. In other words, the said intermediate values determine its position in a scale of hardness peculiar to the particular iron-carburet in hand.

Given the same iron-carburet pure or impure, as before. To this belong another series of carburets, so generated that while chemical composition remains unchanged, the mode of occurrence of carbon passes from an initial extreme phase to a final extreme phase. In the simple case, where carbon is present in the combined and uncombined modifications only, $\frac{\text{combined } O}{\text{Total } O} = 0$ may be regarded as the initial phase, $\frac{\text{combined } O}{\text{Total } O} = 1$, as the final phase of occurrence. The character of the variation of thermo-electric hardness with the generating variable—con.

veniently termed qualitative carburization—cannot as yet be enunciated. The totality, or whole class of iron-carburets of which the given sample is a particular member, finally, may be expressed by a diagram in three dimensions, in which thermo-electric hardness appears as ordinate, quantitative carburization (total carbon in per cents.) as one independent variable, x , qualitative carburization as the other independent variable, y . In the general equation of such a surface, impurities (S. P. Si. Mn. etc.) including any further modification of carbon, are indicated by arbitrary constants (parameters). Any variation of each or all of these is equivalent to a passage from one definite classification-surface to another.

In constructing the diagram use was made of a class of easily measurable physical properties, thermo-electric hardness and specific resistance, which in the case of iron-carburets, from their simplicity and pronounced character, seem above all others to be adapted for purposes of discrimination and classification. In addition to these, however, both the density and magnetic quality (magnetic moment per unit of mass of permanently saturated *linear* rods) of iron-carburets are similarly, though less conveniently, available. On the basis of the above magnetic researches it may be safely affirmed that the given plan of discussion, if applied in turn to these functions, must lead to a classification-diagram differing in no essential respect from the above.

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APPENDIX.

ON THE RELATION BETWEEN THE THERMO-ELECTRIC PROPERTIES, THE SPECIFIC RESISTANCE, AND THE HARDNESS OF STEEL (1879).¹⁷⁵

1.—INTRODUCTORY REMARKS.

The experiments which gave rise to the following paper were commenced with the view of further studying the relation between the maximum of permanent magnetism, hardness, and form of steel, a subject proposed for inaugural work by Professor Kohlrausch.

Although this question has elicited considerable experimentation ever since Coulomb's¹⁷⁶ time, it was not until comparatively recently that harmonious results were arrived at, chiefly through the labors of Ruths,¹⁷⁷ Rowland,¹⁷⁸ Gaugain,¹⁷⁹ Fromme,¹⁸⁰ Trève and Durassier,¹⁸¹ and Gray.¹⁸² All these observers, however, classified steel, with reference to its hardness, either simply into hard and soft, or accepted the colors of the oxide film on the tempered bar as a criterion of distinction sufficient for their purposes. It seemed, therefore, that the most probable method of further elucidating the magnetic subject referred to would consist in attempting to find some method by which the hardness of steel can be more distinctly and more rationally expressed. My endeavor was, in other words, to give the very vague notion hardness, as applied to steel, a *quantitative* signification. So long, however, as the ultimate nature of hardness does not admit of accurate definition, it is sufficient for the accomplishment of this end to examine some of the other properties of steel, which likewise vary with its hardness, and by considering the magnetic moment, *cæteris paribus*, as dependent on the former, to eliminate, as it were, the notion of hardness between them. My attempt is, in short, to find an expression of the more complicated functions of

¹⁷⁵ This is here printed for its bearing upon the discussion of steel, in the form of its original publication in the Phil. Mag. (5), VIII, pp. 341-368, 1879.

¹⁷⁶ Coulomb: Biot. Phys. III, p. 108, &c.; Hansteen: Pogg. Ann., III, p. 236, 1825; Müller: Pogg. Ann., LXXXV, p. 157, 1852; Plücker: Pogg. Ann., XCIV, p. 28, 1855; Wiedemann: Pogg. Ann., CVI, p. 169, 1859; Lamont: Handbuch. d. Magnet., pp. 223, 249-253.

¹⁷⁷ Ruths: Inaugural Dissertation, p. 34. Darmstadt, 1874.

¹⁷⁸ Rowland: Phil. Mag. (4), L, p. 361, 1875.

¹⁷⁹ Gaugain: Comptes rend., LXXXII, p. 145, 1876.

¹⁸⁰ Fromme: Gött. Nachr., No. 7, 1876, p. 157 *et seq.*

¹⁸¹ Trève and Durassier: Ann. de Chim. et de Phys. (5), V, p. 266, 1875.

¹⁸² Gray: Phil. Mag. (5), VI, pp. 321-3, 1878.

hardness, *cæteris paribus*, in terms of the more simple. Of the latter, the thermo-electric properties and the specific resistance of steel, both admitting of accurate and easy determination, appear most suitable.

But the experiments on hardness and the electrical properties alluded to, although only introductory in their character, gave rise to a number of new results. I determined, therefore, to publish them separately. To obtain as complete a picture as possible of these phenomena I have made free use of all the information on the subject within my reach. In each case the author borrowed from is cited.

2.—APPARATUS FOR HARDENING THIN STEEL WIRE.

For reasons which become apparent below¹⁸³ the principal experiments of the following paper are confined to thin rods cut from the same coil. The rather difficult task of hardening these homogeneously throughout their length, without giving rise to a change in their chemical composition (either from oxidation or carburization), I believe to have accomplished by the aid of the following apparatus:

A glass tube 200 to 300 millimeters long, 8 millimeters wide, was provided at a distance of about 80 millimeters from one end, with two opposite apertures *aa*, Fig. 26, each about 3 millimeters in diameter.

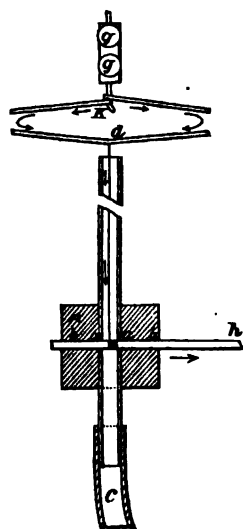


FIG. 26.—Apparatus for hardening.

This part was then surrounded with a cork, *A*, perforated perpendicularly to the axis of the tube in a manner to correspond with the holes *aa*. This arrangement is fastened vertically in a suitable iron stand (not shown in the figure). The wire to be hardened is introduced into the tube and fastened below to a brass rod, *bh*, fitting tightly in the perforation *baab*, and above to the spring *dK*. For the purpose of fastening the lower end it was found sufficient, after having previously wound it around the rod *bh* so as to form a coil which could easily be made to slide off, to push the rod through *baab* and the coil, the latter having been introduced into the tube from the top. The spring *dK*, round the lower half of which the other end of the wire was wound, the upper half being provided with a clamp-screw *gg*, was fastened to a second arm of the stand (also omitted in the figure). By properly adjusting the rod *bh* and the arms of the stand the wire could be brought into coincidence with the axis of the tube and stretched as far as was necessary.

¹⁸³ Difficulties due to structure, *vide* § 7, d.

A powerful galvanic current heated the wire to the degree of redness desired. The former entered *gg* and passed back to the battery through *hh* (as shown in the figure). To prevent the oxidation of the wire during the heating, a current of dry CO_2 -gas,¹⁸⁴ was passed through the tube, entering by means of the hose *O* attached to the lower end.

After the wire had attained a steady uniform glow the hose *O* was closed by the fingers, its connection with the carbonic-acid apparatus disadjusted, the open end being connected with a neighboring hydrant instead; hereupon the faucet of the latter was quickly opened, the galvanic current being at the same time interrupted; the water dashing up the tube (as an unbroken column, however) with great velocity, imparts to the wire the hardness desired. Before each experiment the parts of the apparatus were well dried in a current of air.

The apparatus described presents the following advantages:

(1) By employing currents of different intensity, thus heating the wire to different degrees of redness, we are able to obtain corresponding degrees of hardness, which, though scarcely distinguishable mechanically (all appearing equally hard and brittle), have very different effects on the magnetic and electrical properties of steel.¹⁸⁵

(2) From the fact that the wire is kept in a state of continual tension by the spring *dK*, and from the particular method of chilling, the wires remain straight after being hardened.

(3) The very slight oxidation noticeable on the hard wires is probably due to the contact of water and steel in the act of hardening.

Disadvantages, however, arise from the fact that the use of the apparatus is confined to thin bars, and that the wires obtained may be in a state of circular magnetization. This would partly prevent their employment in (certain) subsequent magnetic experiments. The difficulty may however be avoided by opening the galvanic current a little before opening the faucet.

3.—METHODS OF MEASURING THE HARDNESS OF STEEL ELECTRICALLY.

(a) *Thermoelectric position and hardness of steel.*—In this place it will be expedient to leave the special consideration of steel for the moment,

¹⁸⁴ Having accidentally employed moist carbonic-acid gas, a small flame was observed at the top of the tube. This is probably due to the combustion of H_2 and CO , the former being generated by the decomposition of aqueous vapor by the hot steel, the latter by the action of the nascent H produced on the CO_2 .

¹⁸⁵ See IX. The coercive force of steel being a minimum at a point in incipient redness, it is possible that this apparatus might be used in obtaining intense circularly or longitudinally magnetic wires. In the first case, the wires should be cooled without breaking the current; in the second, the wires surrounded by a tube through which, during the act of hardening, a powerful galvanic current flows. (See Holtz, *Wied. Ann.*, VII, p. 71, 1879.)

giving attention to the electromotive force of a thermo-element composed of any two different metals A' and A'' .

Kohlrausch¹⁸⁶ has shown that the phenomena included under the head of thermo-electricity can be explained on the hypothesis that the heat current is always accompanied by an electric current, whose intensity is proportional to the number of caloric units passing the same section. He thus arrives at an expression for the electromotive force between any two metals (A' and A'') which, if for simplicity we suppose the cold end to be kept at zero,¹⁸⁷ has the following form:

$$E_{\tau} = [S' - S''] \tau [1 + f(\tau)]$$

where E_{τ} is the electromotive force corresponding to the difference of temperature, τ , of the ends; $(S' - S'')$, a constant, specific for the combination.

This expression of Kohlrausch is very convenient, inasmuch as it allows us to separate the actual electromotive force into two terms, of which the first,

$$S' \tau [1 + f(\tau)]$$

is dependent only on the metal A' and τ , the second, $S'' \tau [1 + f(\tau)]$, only on A'' and τ .

Now, we know that the thermo-electric position of a metal is dependent not only on its chemical nature, but also on its mechanical condition (hardness). Let us therefore put

$$S' = S'_0 + \theta' \quad S'' = S''_0 + \theta''$$

where S'_0 and S''_0 are to represent the (absolute) constants dependent on the chemical nature of A' and A'' , respectively, θ' and θ'' , however, varying with the hardness of the metals. Thus the above equation becomes:

$$E_{\tau} = [S'_0 - S''_0] + [\theta' - \theta''] \tau [1 + f(\tau)]$$

But suppose that A' and A'' are not different metals, but represent two rods to which different degrees of hardness have been imparted, which were originally, however, cut from the same wire. In this case $[S'_0 - S''_0] = 0$, whence

$$E_{\tau} = [\theta' - \theta''] \tau [1 + f(\tau)]$$

dependent only on τ and the difference of hardness of the rods.

It will be shown below that the electromotive force of an element of soft and hard steel varies continuously with the difference of temperature τ and with the difference of hardness of the rods. We will therefore put θ'' , the constant belonging to the soft bar (i.e., one which has been heated above redness and allowed to cool slowly in a badly conducting medium), equal to zero, as it is in this that the molecules will

¹⁸⁶ Kohlrausch: Pogg. Ann., CLVI, p. 601, 1875.

¹⁸⁷ The thermo-electromotive force being, according to Tait, Avenarius, Hankel, and others, a function of the temperature of the two ends.

most probably have assumed normal positions. If, furthermore, we replace $E_r = \theta' \tau [1 + f(\tau)]$ by $E_r = a\tau + b\tau^2$, a sufficient approximation for practice, we derive $\frac{dE_r}{d\tau} = a + 2b\tau$ and $\left[\frac{dE_r}{d\tau}\right]_0 = a$, for $\tau = 0$.

This expression, i. e., the limiting value of the electromotive force of a thermo-element composed of a soft rod and one of any degree of hardness to the corresponding difference of temperature¹⁸⁸ when the latter converges towards zero, will, in the sequel, be taken as the measure of hardness of the harder bar. I shall apply the term thermo-electric hardness abbreviated (T. E. H.) to it, throughout the following paper.

The relation between the thermo-electric properties and the hardness of steel, notwithstanding its comparative importance, has never to my knowledge been made the subject of detailed and exclusive study. All the experiments thus far published (the principal being those of Magnus,¹⁸⁹ Sir William Thomson,¹⁹⁰ and E. Becquerel¹⁹¹), are of a qualitative nature, the results being derived from the direction of the current observed on bringing together, in one way or another, wires of different hardness.

The experiments of Magnus, being limited to hard-drawn wires, do not properly fall within the scope of the present paper. The same is true of a number of the experiments in the excellent paper of Sir William Thomson. With regard to the effects of annealing Professor Thomson observes: "In cases of round steel wire, of steel wire flattened through its whole length by hammering, and of steel watch-spring, the thermo-electric effect of annealing portions after the whole had been suddenly cooled, was a current from unannealed to annealed through hot." This result comprehends all that has thus far been done.

(b) *Specific resistance and hardness of steel.*—With reference to the specific resistance and the hardness of steel, I shall proceed in a manner analogous to the preceding. Denoting the observed specific resistance of a bar by S , that part of S which is due only to the chemical nature of the rod by S_0 , that due to hardness by ΔS_0 , I have

$$S = S_0 + \Delta S_0$$

Now, as it follows from results given below that the specific resistance of steel increases continuously with its hardness, it will be convenient to put ΔS_0 for the soft bar equal to zero. The value of ΔS_0 for a bar of any degree of hardness, thus numerically determined, will in the following be accepted as a second measure of that property. The work thus far published on the relation between specific resistance and

¹⁸⁸ The colder end being supposed at 0°.

¹⁸⁹ Magnus: Pogg. Ann. LXXXIII, p. 486, 1851.

¹⁹⁰ Thomson: Phil. Trans., III, pp. 709-727, 1856.

¹⁹¹ Becquerel: Ann. de Chim. et de Phys., (4), VIII, p. 402, 1866.

hardness of steel is due principally to Mousso¹²². Of late, results have been announced by Chwolson.¹²³ The data of both observers agree only qualitatively with mine, and among themselves.

4.—DETERMINATION OF THERMO-ELECTRIC HARDNESS. APPARATUS.

(a) *Method of measurement.*—In the determination of thermo-electric force the procedure known as Ohm's method was first employed. Afterwards it was found expedient to measure these forces (as Kohlrausch and Ammann¹²⁴ had done in similar experiments before) by a zero method, the object being to avoid the species of polarization due to Peltier's phenomenon. My method can easily be deduced from that proposed by Bosscha, the latter, in the case where small electromotive forces are to be measured, admitting of simplification. In the diagram, Fig. 27,

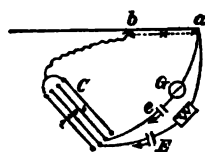


FIG. 27.—Disposition of apparatus.

E denotes the compensating element (1 Daniell's element = 11.7 Weber $\times$ Siemens' units), e the thermo-couple whose electromotive force is to be determined, both acting as shown in the figure, C a Weber's commutator (employed for reasons given below), G the galvanoscope. Let the resistance of the branch ab be represented by x , that of the branch aEb by $W+k$, where W represents the large resistance of a rheostat interposed, k that of the remainder of the branch (about equal to 1 Siemens' unit) including E . When the current in G is zero we have,

$$\frac{e}{E} = \frac{x}{W+k+x}$$

But as $\frac{e}{E}$ is small, and therefore of necessity also x (maximum value = 10 S. U.), in comparison with $W+k+x$ (20,000 Siemens' units), I may with sufficient approximation, put

$$e = \frac{E}{W} x$$

the experimental accuracy attainable allowing me to neglect $(k+x)$ in comparison with W . In the experiments the branch ab was a small Siemens' rheostat.

The precise moment at which the current in the galvanoscope is zero can be best determined by observing whether the needle on closing and opening the circuit remains at rest. This, however, is only possible when the opposed currents from e and E which pass through the galvanoscope are closed simultaneously. To accomplish this the little

¹²² Moussoⁿ: N. Deusch. d. Schw. Gesellsch. (8), XIV, pp. 1-90, 1855.

¹²³ Chwolson: M $\acute{e}$ l. Phys. de St. P $\acute{e}$ tersbourg, X, p. 379, 1877. See also Carl's Repert., XIV, p. 15, 1878.

¹²⁴ Kohlrausch and Ammann: Pogg. Ann., CXLI, p. 450, 1870.

cups at the end of the rods 1 and 2 of the commutator were quite filled with mercury, those of 3 and 4 only partially. By this device, on closing, C_1 and C_2 are first brought into contact, and the current $EC_2 C_1$ *ba WE*, not passing through the galvanometer, comes into action; in the next moment (C_3 and C_4 being joined) the current from e and the partial current from E referred to are closed simultaneously. In this way also induction-currents which may possibly be generated in the rheostat, are without disturbing effect. The commutator merely serves the purpose of a double key.

As the electromotive forces to be measured were all very small, the large resistance W could be left unaltered, so that $e = \text{const. } x$. Now, the resistance x was so chosen that the intensity of the current from e exceeded that of the partial current from E by the minimum possible. The thermo-electric force, however, decreasing with the temperature, $T - t = \tau$ of the ends, a moment soon arrives at which the intensities of the two currents are equal, and the deflection of the needle = 0, in consequence. At this point the thermometers are read off.

(b) *Description of thermo-element.*—Instead of measuring the electromotive force of soft and hard steel directly, it was found expedient to compare all the rods with one and the same piece of copper wire. By this means the apparatus could be considerably simplified and many practical difficulties avoided. The construction of the copper-steel couple is given in vertical section in Fig. 28.

To raise the ends of the rod to different temperatures two doubly-tubulated receivers, each about 10 centimeters in diameter, were used. These, held in position by movable supports of poorly-conducting material, and so placed that the tubulures A and B were horizontal, the other two vertical, were connected by a glass rod cd fitting water-tight in the perforated corks adapted to the horizontal tubulures. This rod served a double purpose. By uniting the receivers as one it prevented breakage of the very brittle steel rods, at the same time allowing the receivers to be easily adjusted and removed; on the other hand the receivers could by means of it be placed at any distance apart, this being necessary, as the rods to be examined were of very different lengths.

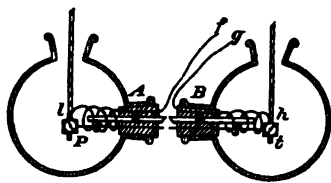


FIG. 28.—Original form of thermo-element.

On one side of the glass rod the copper wires which acted as poles of the instrument were inserted once for all; on the other two appropriate holes served for the introduction of the steel rods ss to be tested. The ends of the latter were connected with the corresponding ends of the copper wires by small flat clamp-screws of brass.

The apparatus being thus ready for experiment the two receivers were filled with distilled water at T° and t° , respectively, where t was so chosen as to differ but slightly from the temperature of the room.

The thermometers (introduced through the vertical tubulures) were read off with a telescope as follows: The deflection of the needle having become very small, t was determined, after which, when the current in $G = 0$, T , whereupon another check-reading of t was made. Before each observation the water in the receivers was well stirred.

(c.) *Galvanoscope*.—The galvanoscope used was a very delicate instrument of Sauerwald's, provided with mirror and astatic needle. The deflection of the latter was read off with telescope and scale. As the telescope of this instrument stood side by side with the telescope for the thermometers, both readings could conveniently be made by the same observer.

5.—DETERMINATION OF SPECIFIC RESISTANCE.

For determining the specific resistance of steel rods use was made of Wheatstone-Kirchhoff's bridge. An appropriate commutator allowed the observer to exchange the unknown resistances without altering the value of those belonging to the bridge proper. Thermo-electric disturbances were avoided as far as possible by closing the current (1 Smea with large resistance) only for very short intervals of time. Finally they were eliminated completely by replacing the hydro-electromotive force by Weber's magneto-inductor.¹⁹⁶ The resistances of all rods were determined in terms of an arbitrary standard δ (0.0312 Siemens unit at 0°), chosen to correspond in magnitude with the unknown resistances. The galvanometer used was the one already mentioned above.

As the resistances to be measured were all very small (0.1 to 0.01 Siemens unit), great care had to be taken to exclude all disturbing resistances due to insufficient contact. Soldering could not be resorted to, as it was believed that the ends would thereby be annealed. The method adopted was as follows: The ends of the rods having been well cleansed were covered to about 1 centimeter with a thin adhesive film of galvanically deposited copper, which was thereupon amalgamated (easily accomplished by plunging the freshly-covered part in mercury). The rod thus prepared was then fixed together with a glass rod in two corks, in a manner similar to that employed in the case of the thermo-element, and the whole, except the amalgamated ends, covered with a thick coat of varnish. Suitable wooden cups, provided with horizontal and vertical apertures, completed the connection of the rods with the respective parts of the bridge by means of mercury.

The efficient length was determined by deducting from the total length that of the amalgamated ends. For the measurement of diameter use

¹⁹⁶ Weber: Pogg. Ann., CXLII, p. 418, 1871. The use of the magneto-inductor in connection with the bridge was suggested by Kohlrausch. This physicist also showed that the method is applicable even when the resistances to be determined are in form of coils, the extra currents produced being calculable. I found the application of great convenience, inasmuch as the observer always has the needle of a delicate galvanometer completely under his control.

was made of the microscope. A determination of this dimension from known weight, specific gravity, and length was impracticable, inasmuch as the use of the pycnometer, which alone would have given sufficiently accurate results, would have compelled me to break the rods.

6.—EXPERIMENTAL RESULTS.

A. Thermo-electric hardness of rods suddenly immersed in cold water while in different states of red heat.—The following (older) results were obtained directly by Ohm's method. E_r was put = constant τ , a condition nearly fulfilled by couples of soft and hard steel between zero and 80° , in which case T. E. H. and the constant of proportionality are identical. The rods were hardened in the apparatus described in § 2; diameter = 0.0678 cm.; the numbers preceded by the point (.) were afterwards checked by the method of compensation. T. E. H. is expressed in Weber $\times$ Siemens units.

The third column of the following table contains the number of large Bunsen cells employed in heating the wire, the fourth the observed degree of redness at the time of sudden cooling.

TABLE I.

No.	T. E. H.	Bunsen elements.	Remarks.
1	0.000004		Soft, cooled slowly from red heat.
.2	0.000003	4	Below redness.
.8	0.000012	5	Ignited dark red.
.4	0.000000	5	
.5	0.000000	6	
.6	0.000000	6	
.7	0.000052	7	
.8	0.000049	7	Ignited brick red.
.9	0.000054	7	
.10	0.000056	8	
.11	0.000057	8	
.12	0.000063	8	
.13	0.000064	9	
.14	0.000065	9	
.15	0.000064	9	

The Bunsen cups were introduced without altering the remaining part of the circuit. The length of the wire heated was not in all cases the same.

B. Further thermo-electric data. Hard steel.—The following determinations were made in the summer of 1878; temperature of the room very constant and at about 20° , this, as already observed, being nearly the same as t , the temperature of the water in the colder receiver. The method of compensation was employed throughout. The determination of T was effected by a Geissler normal thermometer (graduated in $0^\circ.1$), that of t by an ordinary instrument (graduated in $0^\circ.2$) which had, however, been carefully compared with the former.

In Tables II and III the difference of temperature of the ends of the steel rod is given under τ , the corresponding electromotive force for the elements copper-steel under E_r ; α and β are constants which satisfy

the equation $E_r = a\tau - \beta\tau^2$. These were calculated by first computing their approximate values out of two distant observations, and then adding to them corrections deduced from five of the most satisfactory observations, by the method of least squares.

If, now, we denote by a and b the constants of an element soft-steel and hard-steel, corresponding to those a, β, a', β' of the same rods, when compared with copper, we shall have, since $E_r = a\tau - \beta\tau^2$ and $E'_r = a'\tau - \beta'\tau^2$,

$$E_r - E'_r = (a - a')\tau - (\beta - \beta')\tau^2$$

But $E_r - E'_r = E_r$, the electromotive force of the element steel-steel; so that, since also $E_r = a\tau - b\tau^2$,

$$a = a - a' \quad b = \beta - \beta'$$

The constants a and b are given in the last two columns. a may be regarded as numerically equal to the T. E. H. above defined, as E_r is nearly a linear function of τ .

TABLE II.—Rods 0.0678 centimeters thick.

No.	τ	E_r Observed.	E_r Calculated.	a	β	$a = \text{T. E. H.}$	b
I	13.92	0.001464	0.001457	0.0001071	0.0000001738	Nil	Nil
	25.68	2635	2636				
	39.78	3981	3985				
	49.84	4859	4862				
	62.65	6081	6080				
II	17.90	0.001815	0.001807	0.0001038	0.0000001629	0.0000031	0.000000184
	31.39	3104	3100				
	47.58	4567	4572				
	56.53	5328	5349				
	63.72	5972	5966				
IV	20.25	0.001112	0.001095	0.00005811	0.0000002006	0.0000490	-0.000000273
	29.20	1522	1526				
	46.50	2283	2268				
	59.90	2752	2761				
	61.35	2810	2810				
V	18.07	0.000678	0.000681	0.00005156	0.0000001568	0.0000555	0.000000165
	21.93	1054	1056				
	47.76	2108	2105				
	61.32	2576	2571				
	63.44	2635	2640				
VI	15.75	0.000703	0.000700	0.00004880	0.0000001390	0.0000605	0.0000000342
	31.84	1347	1343				
	43.51	1756	1785				
	45.06	1815	1818				
	59.42	2283	2278				
VII	19.04	0.000761	0.000764	0.00003807	0.0000001529	0.0000641	0.0000000294
	34.08	1288	1288				
	53.64	1874	1867				
	68.40	2108	2112				
	68.80	2225	2225				
VIII	18.42	0.000644	0.000658	0.00003807	0.0000001279	0.0000690	0.0000000454
	31.15	1054	1082				
	45.00	1464	1454				
	62.10	1874	1871				
	65.40	1932	1943				
IX*						0.000700	

¹ Heated above redness and allowed slowly to cool in wood ash; "soft."

² Heated galvanically below redness, then suddenly cooled; "soft."

³ Heated to dark redness, then suddenly cooled; "glass-hard."

⁴ Heated to redness, then suddenly cooled; "glass-hard."

⁵ Heated galvanically to brick-redness, then suddenly cooled; "glass-hard."

⁶ Heated galvanically to brick-redness, then suddenly cooled; "glass-hard."

⁷ Heated to yellow-ignition, then suddenly cooled; "glass-hard."

⁸ Heated to yellow-ignition, then suddenly cooled; "glass-hard."

* This determination was made at a later date; with reference to its accuracy the remarks under C and D apply.

TABLE III.—Rods 2.65 millimeters thick, tempered by Mr. Barth, mechanician.

No.	τ	E_{τ} Observed.	E_{τ} Calculated.	α	β	$\alpha = T. E. H.$	b
¹ D	32.28	0.002928	0.002918	0.00009447	0.0000001287	0.00001263	0.0000000478
	45.55	4040	4042				
	46.58	4157	4153				
	55.54	4860	4859				
	56.24	4918	4915				
² C	20.32	0.001639	0.001628	0.00008285	0.0000001229	0.00002445	0.0000000504
	31.98	2318	2517				
	32.90	2576	2386				
	47.98	3689	3078				
	49.80	3806	3811				
³ B	32.40	0.001991	0.002004	0.0000646	0.0000000864	0.0000424	0.0000000869
	33.08	2049	2044				
	50.47	3045	3043				
	61.00	3630	3621				
	62.25	3689	3690				
⁴ A	10.86	0.000117	0.000121	0.00000999	0.0000001068	0.00011710	0.0000000665
	27.20	351	351				
	43.75	644	642				
	58.12	837	842				
	60.37	995	993				

¹ Soft; gently ignited, slowly cooled.² Tempered dark yellow.³ Tempered blue.⁴ Glass-hard.

* This rod (as also those of the following section C) is electronegative with reference to copper.

B'. Specific resistance of the same material.—The following Tables IV and V contain the specific resistances of the rods already cited in Tables II and III. The data are given in terms of mercury. The column S contains the total specific resistances, ΔS_0 the corresponding excess of the latter over that of the normal rod I. Of the ratio $\frac{\Delta S}{T. E. H.}$ mention will be made hereafter.

Let the resistances of the two parts of the first branch of the bridge, on each side of the sliding contact, be denoted by a and b ; let the resistances of the corresponding parts (thick copper wire) of the second branch of the bridge be denoted by K' and K'' . Into the latter the unknown resistances W and R are to be inserted, respectively. Finally, let δ be the standard of comparison above referred to, in terms of which W and R are to be measured. When the current in the galvanometer is zero, we shall have for a particular position of the commutator:

(1) W and R alone—

$$\frac{a}{b} = \frac{W + K'}{R + K''}$$

(2) W and R with δ on the right—

$$\frac{a'}{b'} = \frac{W + K'}{R + K'' + \delta}$$

(3) W and R with δ on the left—

$$\frac{a''}{b''} = \frac{W + K + \delta}{R + K''}$$

Three similar equations may also be derived from the other position of

the commutator, as only W and R are interchanged. From these six equations we deduce:

First position—

$$\frac{W}{\delta} + \frac{K'}{\delta} = \frac{1}{\frac{b'}{a'} - \frac{b}{a}} \qquad \frac{R}{\delta} + \frac{K''}{\delta} = \frac{1}{\frac{b''}{b'} - \frac{b}{a}}$$

Second position—

$$\frac{W}{\delta} + \frac{K''}{\delta} = \frac{1}{\frac{b'}{a'} - \frac{a}{b}} \qquad \frac{R}{\delta} + \frac{K'}{\delta} = \frac{1}{\frac{b''}{b'} - \frac{a}{b}}$$

$\frac{K'}{\delta}$ and $\frac{K''}{\delta}$ were determined in the same way previous to the experiments, and their values checked from time to time. In comparing the resistances $I \dots IX$ and $A \dots D$, the following plan was observed:

$W: \delta$	I	IV	IV		VIII	VIII	I	} And in the same way with A to D .
$R: \delta$	II	II	V		VII	IX	IX	

Each of the data is therefore derived as a mean of four determinations. Possible heterogeneity of the wire $a+b$ thus becomes less effective.

As an example, I will add results obtained for the rod C (resist.= 0.0051 Siemens units):

		Compared with A .	Compared with B .	Compared with D .
1st position.....	$W: \delta =$	0.1648	0.1654	0.1649
2d position.....	$W: \delta =$	0.1639	0.1632	0.1639
	Mean..	0.1639	0.1643	0.1644

For the rod I (resistance=0.0542 Siemens units) on different occasions, 1.735 and 1.741 were found for $W: \delta$.

As will be seen, the principal stress was put on relative values of the resistances. To facilitate orientation, however, the results were approximately reduced to Siemens units by determining the standard δ in that denomination.

Assuming the coefficient for temperature for steel to be the same as that for copper, the results obtained will be good for $0^\circ C$ directly, δ having been previously reduced. Although this is only approximately true, the influence of this difficulty on the relative values of the resistances will be but slight, as the temperature of the room remained nearly constant.

TABLE IV.

No.	Resistance.	S	ΔS_0	$\frac{\Delta S_0}{T. E. H.}$
I..	0.05417	0.1381	Nil.	-----
II..	0.04305	0.1400	0.0039	1280
*IV ¹ .	0.11130	0.2337	0.0976	1990
V..	0.11060	0.2463	0.1122	2020
VI..	0.07846	0.2592	0.1281	2030
VII..	0.08740	0.2648	0.1287	2010
VIII..	0.15330	0.2779	0.1418	2050
*IX..	0.09417	0.2810	0.1449	2070

¹The resistances marked with an asterisk were determined by using the magneto-inductor as a current generator. In the others a Smee element was employed.

TABLE V.

No.	Resistance.	S	ΔS_0	$\frac{\Delta S_0}{T. E. H.}$
D	0.00209	0.1654	0.0293	2320
C	0.00512	0.2065	0.0704	2860
B	0.00595	0.2271	0.0910	2150
A	0.00908	0.3804	0.2445	2090

The experiments now following, under the heads *C* and *D*, have more a descriptive character than one of precise measurement; the results are therefore given with one decimal less. For the determination of T. E. H. the rods coming under these heads were compared indirectly with rod VIII (Table II) for the T. E. H., of which the number 0.000069 (as above found) was assumed.

C. T. E. H., and ΔS_0 for glass-hard rods, diameter=2.30 millimeters.—These were hardened by the aid of the blast lamp. The flame of the latter was for this purpose directed horizontally and placed directly over a trough containing cold water. In this way the red-hot rod could be transferred with great rapidity out of the flame into the water.

TABLE VI.

No.	T. E. H.	Resistance.	S	ΔS_0	$\frac{\Delta S_0}{T. E. H.}$	Remarks.
*[I]	0.000138	0.0121	0.421	0.285	2100	Ignited yellow and chilled.
*[II]	131	-----	-----	-----	-----	Do.
[III]	130	-----	-----	-----	-----	Do.
*[IV]	130	0.0129	0.443	0.306	2300	Do.
[V]	116	107	0.336	0.230	2000	Ignited red and chilled.
*[V]	136	123	0.430	0.294	2200	} [III] u. [V] Twice re-ignited yellow and chilled.
*[III]	133	-----	-----	-----	-----	

D. T. E. H. and ΔS_0 , of rods 0.678 millimeter in diameter, hardened¹³⁶ in the apparatus §2, afterwards annealed by immersion in hot linseed oil.

¹³⁶The T. E. H. of these rods in the glass-hard condition varied from 50:10° to 60:10°.

TABLE VII.

No.	T. E. H.	Resist- ance.	S	ΔS_0	$\frac{\Delta S_0}{T. E. H.}$	Remarks.
*1	0.000010	0.0540	0.157	0.021	2100	Glass-hard and gradually heated to 300° in linseed oil. ¹
*2	13	0616	158	022	1700	
*3	11	0537	158	023	2100	
*4	14	0691	163	027	1900	
*5	12	0592	166	030	2500	
*6	18	0793	177	041	2300	Similarly annealed at 280°.
*7	24	0659	185	049	2000	
*8	33	0740	205	069	2100	
*9	31	0807	206	070	2200	Similarly annealed at 240°.
*10	36	0731	208	073	2400	Similarly annealed at 200°.
*11	57	0.1088	250	114	2000	Similarly annealed at 150°.
*12	58	0.1135	261	125	2200	
Soft iron.	-0.000004	0.0420	0.133	-0.003	750	Heated to redness in Bunsen's blast-lamp and slowly cooled.

¹ Rods 1 to 5 remained in the bath during the whole process; the others were immersed but for 2" to 3". The temperature at which the rods 6 and 7 were annealed could not be determined with certainty, a microscopic air-bubble in the neck of the mercury reservoir having given rise to rupture of the thread.

E. Corroborative measurements.—The resistances thus far determined being very small, it was feared that in spite of the continuity apparent in their variation, errors from insufficient contact might have conspired in producing illusory results. For these reasons check-experiments with longer wires were made, the resistance of some of which (I to V) is sufficiently great to admit of direct comparison with the Siemens mercury unit (étalon). To insure a more homogeneous hardening, these wires were spirally wrapped around a round stick of wood, and the length and diameter of the coils resulting so determined that the whole during the process of heating could be brought within the mantle of the blast-flame. In other respects the method given under *C* was pursued.

TABLE VIII.

No.	Resist- ance.	Length.	Diam- eter.	S	ΔS_0	Remarks.
I	0.643	0.880	0.67	0.260	0.124	Ignited yellow; then suddenly cooled.
II	379	917	96	296	160	Do.
III	245	928	1.19	293	157	Do.
IV	121	932	1.83	342	206	Ignited red; then suddenly cooled.
V	105	656	1.62	391	235	Ignited light yellow; then suddenly cooled.
*VI	0169	733	2.15	354	218	Ignited red-yellow; then suddenly cooled.
*VII	0156	732	2.15	325	189	Ignited red-yellow; but ends darker.
*VIII	0169	740	2.15	352	216	Ignited red-yellow; then suddenly cooled.

Spirals II and IV were afterwards softened by heating to redness in a Bunsen burner. Their specific resistance in this condition was found to be

$$*II. S_0 = 0.154$$

$$*IV. S_0 = 0.159$$

Finally, in order to compare the results obtained with induction currents with those in which a Smee element was employed, certain of the experiments were repeated. The agreement was entirely satisfactory.

7.—HARDNESS AND THERMO-ELECTRIC PROPERTIES OF STEEL: DEDUCTIONS AND SUPPLEMENTARY EXPERIMENTS.

(a) *Thermo electric and mechanical hardness.*—From the data contained in Tables II, III, and VII, we derive that the thermo-electric position of steel progresses continuously with its degree of hardness, or, in other words, thermo-electric and mechanical hardness are direct functions one of another.

This statement involves the assumption that the rod cannot pass from the glass-hard (maximum) to the soft state (minimum) without passing through every intermediate stage; or that by proper methods of annealing, every state between the maximum and minimum can be produced. This, I dare say, will generally be admitted.

As of further interest I may add: (1) that rods cut from the same wire and glass-hardened in the same way possess also the same thermo-electric hardness (Table VI); (2) this is the case even when the rods are carefully rehardened (rods [III]', [V]', Table VI); (3) that if we start from like maxima, the thermo-current always passes from less to more annealed, through warm. (The direction of the current was independently observed.)

(b) *Variation of T. E. H. with differences of material and of thickness.*—From an examination of the data obtained for different material, we infer that the T. E. H. of soft and similarly annealed rods approximates to the same value;¹⁹⁷ that the value of this constant for glass-hard rods is remarkably different. The rods in Table VI, for instance, possess a T. E. H. amounting nearly to $140:10^6$; whereas in the rods in Table II the maximum¹⁹⁸ value found does not exceed $70:10^6$. This may be due to a difference in thickness, or, more probably, to a difference in the composition of the rods examined.

These phenomena were further studied through the following experiments:

1. Commercial rods of different diameters were glass-hardened and examined with reference to the current produced when one end of a couple was cooled with a wedge-shaped piece of ice. In general a maximum of T. E. H. was observed in rods whose diameters lay between 1 and 2 millimeters. These experiments, however, are unsatisfactory, inasmuch as the composition of the rods enters as an element of dis-

¹⁹⁷In order to compare the degree of hardness corresponding to a particular oxide tint with that corresponding to a given temperature of the oil bath, use was made of the tables found in Frick's *Physikal. Technik*, 3 ed., p. 377; also Wagner, *Chem. Tech.*, 8 ed., p. 29. On the authority of these works 230° corresponds to yellow, 290° to blue, annealed. We should therefore expect rods 6, 7, and 8, 9 (Table VII) to agree with the rods C and B (Table III) respectively. This is sufficiently the case.

¹⁹⁸These rods (Table II), even when heated to the utmost white and suddenly cooled, remained strongly electro-positive towards copper. T. E. H., even in this extreme case, was much less than $107=10^6$.

turbance which cannot be allowed for. For this reason experiments were made on thick bars, the parts of which had been filed to different diameters.

2. The halves of each of two pieces cut from the same rod, 5 millimeters in diameter, were reduced¹⁹⁹ by filing to thicknesses of 3 millimeters and 1 millimeter, respectively, and glass-hardened. During the process of heating care was taken to raise all parts of the bars to the same degree of redness. On connecting the ends with the galvanometer and applying the ice wedge at the middle (where the diameter enlarged), very decided currents were observed, passing from thin to thick through warm. Hereupon two cones were filed of the same material (5 millimeters thick at base and 50 millimeters long). Point and base of the cones (previously glass-hardened) being connected with the galvanoscope, the ice wedge applied at any point produced in each case currents from apex to base through warm, thus harmonizing with the previous experiments. Near the points only the results became uncertain. On bringing together the cones with the rod [IV] (Table VI) the points were found to be thermo-electrically harder, the base softer than the rod. On the other hand, the point of a fine needle prepared from the same material gave contrary indications. The point, therefore, was apparently softer than rod IV.

3. Finally two very gradually tapering cones were prepared from another steel rod, 2.8 millimeters in diameter. Connection with the galvanometer being made, the application of the ice wedge to parts near the base generated a current from thin to thick through warm; to parts near the apex, a current in the opposite direction. Finally, between these a position was found at which the application of the ice wedge produced no current at all. This occurred at parts about .5 millimeters in diameter. The other cone gave like results.

4. When the bases of two similar cones of the same materials are connected with the galvanometer and their apices brought in contact, upon warming the latter, a current in one direction or another will be produced; this from the fact that the points are rarely equally hard. Experiment shows that by consecutively warming parts which lie symmetrically to the right and left of the apices in contact, currents in opposite directions are the effect. Herefrom it follows that the currents originate each in a single cone.²⁰⁰

5. In endeavoring to generalize from these experiments, attention must be paid to the following points: *a*, the maximum value of T. E. H. attainable is dependent on the quantity of carbon contained in the steel. The thermo-electric difference between rods of soft and sud-

¹⁹⁹ It is to be observed that the thinner parts of these pieces sooner arrive at red heat and remain longer in this condition than the thicker parts. This applies equally to the cones.

²⁰⁰ The experiments with two separate cones were equally successful when the conical forms were only part of the same continuous piece.

denly cooled wrought iron can, for instance, be neglected in comparison with the corresponding difference between hard and soft steel. *b*, T. E. H. is influenced by the temperature of the rod when suddenly chilled (VII *c*), as well as by the time of heating, the latter affecting the composition. *c*, By the form of the piece of steel and the method of sudden cooling, the internal structure of the mass being thereby modified (VII *d*). *d*, Finally, we might add that, in the time elapsing between the removal of the rod out of the fire and the subsequent immersion, the loss of heat by radiation will be relatively greater in the case of thin than in the case of thick rods.²⁰¹ With these facts in mind we may conclude that the maximum values of T. E. H. attainable by glasshardening rods of the same composition increases as thickness diminishes; that as this dimension continues to decrease a diameter is reached at which the negative effects of decarburization are equal and finally overcome by the positive effects due to diminution of diameter.

(*c*) *Effect of the temperature from which steel is suddenly cooled in hardness. Chemical and mechanical hardness.*—From the results contained in Table I there follows: The hardness of steel does not increase continuously with its temperature at the moment of sudden cooling, but at a point in dark red heat the glass-hard state is suddenly attained. From this point on, however, the degree of glasshardness (measured electrically) continues to increase with the temperature. This observation conduces to the conclusion that the change of state due to glass-hardening is chemical in its nature. In this opinion, I believe, most chemists at present also concur, it being assumed that the uncombined carbon in soft steel is, by sudden immersion, converted into the chemically combined. In summing up the facts by which the hypothesis is furthermore supported, I will mention in the first place the detailed analogy²⁰² which exists between the white pig (used in the manufacture of Bessemer steel) and glass-hard steel, on the one hand, and ordinary (gray) cast-iron and soft steel on the other; the former containing carbon only in the combined, the latter also in considerable proportion in the uncombined, state. Secondly, hardening by a process of wire-pulling, hammering, etc., will, in all probability increase the specific gravity of steel; hardening by sudden cooling, as is well known, di-

²⁰¹ I will add here (1884) that another possible source of error was overlooked in the above. I refer to the electro-motive force of superficial layers in case of loose contacts, as investigated by Franz (Pogg. Ann., LXXXV, p. 388, 1852), Jenkin (Rep. Br. Assoc., 1861, (2), p. 34), Gauguin (C. R., XXXVI, p. 612-16, 1853, Ann. de Chim. et de Phys. (3), LXV, p. 75-102, 1862) and others. But I feel confident that these phenomena are not contained in the above: 1, because loose contacts were avoided; 2, the metals were always bright and polished; 3, the results were the same when difference in diameter (double cone) occurred in one and the same continuous piece of steel; 4, from the variety of experiments made and the uniformity of the results obtained.

²⁰² See Wagner: Chem. Tech., 8 ed., pp. 14, 15, 29. These analogies refer to mechanical properties, method of preparation, color.

minishes it. In the former case the thermo-electric current usually passes from soft to hard through warm;²⁰³ in the latter, in the contrary direction. In drawn wire the specific resistance is smaller,²⁰⁴ in hard tempered greater than that of the same wire in the soft state.

Considering these facts as a whole, we are perhaps justified in distinguishing between a process of chemical and a process of mechanical hardening. This, however, does not prevent us from paying due regard to a series of physical phenomena which accompany the former. To these the peculiar internal structure of glass-hard bars, the warping which frequently attends sudden cooling, etc., are to be referred. We conclude, therefore, that the cause chiefly influential in bringing about glasshardness in steel is chemical in its nature, and that, in consequence of the physical phenomena which invariably accompany it, the degree of glasshardness is more or less modified. On the latter ground the continual increase of the T. E. H. after the critical temperature above referred to has been reached is to be explained.

(d) The observed T. E. H. can, of course, only be assumed as directly expressive of its hardness when the rod under experiment is homogeneous throughout. In thick bars, which in the glass-hard state may be considered as made up of a series of concentric cylindrical shells, the hardness of which decreases rapidly as we pass from the exterior to the interior, the circumstances become more complicated.

Furthermore, suppose the ends of a thick glass-hard cylinder to be kept at temperatures T and t ($T > t$). In this case, since each of the infinitely thin cylindrical shells has a particular T. E. H. corresponding to its hardness, we are led to infer that thermo-currents, closing themselves in the interior of the cylinder, are the result—the direction of these in the outer harder parts being from t to T , in the inner from T to t . In figure 29 (vertical section) the hypothetical condition of the cylinder in this case is indicated. As will be seen, its electrical state corresponds to that of a rod circularly magnetized.



Fig. 29. — Thermo-currents evolved in a hard thick cylinder.

For the purpose of studying this question experimentally, a steel cylinder, 30 millimeters in diameter and 50 millimeters long, was turned and glass-hardened. This was placed vertically directly before the needle of a magnetometer (the deflection of which could be read off with telescope and scale) in such a manner that the position of equilibrium of the needle was left unaltered.

The relative position of the needle and cylinder, in other words, was such that the axis of the former, if prolonged, would intersect the axis of the latter if prolonged at its middle point. Upon now cooling the

²⁰³ Magnus: Pogg. Ann., LXXXIII, p. 469, 1851; Sir W. Thomson, Phil. Trans., III, p. 722, 1856.

²⁰⁴ Monsson: N. Denkschr. d. Schwz. Gesell., XIV, 8, p. 1-90; Chwolson: Carl's Rep., XIV, p. 15.

upper end of the cylinder with a piece of ice, or warming by projecting a jet of steam against it, very decided deflections were observed toward the right or left, respectively, which increased with the difference of temperature $T-t$, and vanished as this difference became nil.

As the cylinder was not magnetic, it is improbable that these phenomena can be referred to a change in the state of magnetic distribution. With reference to the direction of the currents, however, no simple results could be arrived at.

(e). *Relative thermo-electric qualities of soft steel and soft iron.*—In § 7, c, we ascribed the very high value of the T. E. H. of a glass-hard steel rod to the large proportion of chemically combined carbon contained therein. If this be true, the thermo-electric difference between soft steel and soft iron, in both of which combined carbon is either wholly absent or exists only in traces, must be quite small. This inference is supported by the data actually found for soft iron. Making allowance for the difference of circumstances involved, the result to be derived from the experiments of Kohlrausch and Ammann also agrees sufficiently herewith.

On the other hand, Joule²⁶⁶ has long since shown that ordinary cast-iron is thermo-electrically negative towards copper, all the more, therefore, towards soft steel—a result which I should be inclined to predict from the quantity of combined carbon contained.

The minimum values of T. E. H. (obtained by cooling the red-hot bar as slowly as possible) of different kinds of steel²⁶⁷ and of soft iron are approximately the same; whereas the maximum values of this constant (obtained by cooling the highly heated bar as rapidly as possible) differ enormously; this difference being a direct function of the quantity of carbon contained.

(f) *Thermo-electric effect of magnetization.*—Sir William Thomson²⁶⁷ has shown that in a thermo element, consisting of magnetized and unmagnetized steel of the same hardness and form, thermo-currents due only to magnetic difference are generated. The direction of these currents was found to be in one case from unmagnetized to longitudinally magnetized through warm, in another from transversely magnetized to unmagnetized through warm, therefore also from transversely to longitudinally magnetized through warm.

For the purpose of informing myself of the magnitude of the thermo-electric difference thus produced, the following experiment was made: A soft rod (I, Table II) was tested for its electro motive force when combined with copper (as described above, p. 348), and the locus of the

²⁶⁶ Joule: Phil. Mag. (4), XV, pp. 538-'39, 1857.

²⁶⁷ Steel is here used as distinguished from iron only by containing a greater proportion of carbon. No attention has been paid in this paper to the effects of P, S, Si, Mn, etc., so often present in both.

²⁶⁷ Thomson: Phil. Trans. III, pp. 722-'7, 1856.

equation $E\tau = a\tau - \beta\tau^2$ constructed from *fifteen* very carefully made observations.

Hereupon a large magnetic battery, weighing 40 pounds, was so placed that each of the ends of the horseshoe touched a receiver. The distance between the poles of the magnet and the corresponding ends of the steel rod was thus about 50 millimeters. A second series of fifteen observations was now made. Upon comparing the locus of the latter with that of the former, the two curves coincided so completely that no influence could be discerned.

Herefrom I conclude that the thermo-electric effect due to difference of magnetic state may, in comparison with that which can be produced by a difference of hardness, be completely neglected.

(g) *Relation between T. E. H. and density of steel.*—A very curious analogy was found in comparing the results at which Fromme²⁰⁸ arrived, in studying the specific gravity of differently tempered steel, with the T. E. H. of similar rods as found in my experiments. Dr. Fromme, if I infer correctly, limited his experiments to rods whose diameter was greater than 2 millimeters, and less than 7 millimeters. His results are contained in the following table, the volume of the soft bar being put = unity.

TABLE IX.

	Volume.	Volume-increase.	T. E. H.
Soft	1.000	0.000	0.000 000
Annealed blue	1.002	0.002	0.000 024
Annealed yellow	1.005	0.005	0.000 042
Glass-hard	1.010	0.010	0.000 117

In the fourth column the T. E. H. of rods cited in Table III. (these, as I believe, corresponding very closely to those for which the data of Fromme apply) is added. If we take into consideration that the results were obtained from different material, the parallelism observable is striking. To the very large difference between glass-hard and yellow annealed, when compared with the much smaller difference between yellow and blue, blue and soft, as seen in both observations, I would once more call attention. The fact that glass hard rods can be considerably annealed at comparatively low temperatures must be regarded as an adequate indication of their unnatural (strained) condition.

A second result of Fromme, that the specific gravity of thin rods suffers greater loss by glass-hardening than that of thick rods, also harmonizes with the conclusions drawn in § 7 (b) with reference to the T. E. H. of such rods.

²⁰⁸ Fromme: Götting. Nachr. p. 165, 1876.

8.—HARDNESS AND SPECIFIC RESISTANCE OF STEEL: DEDUCTIONS.

From the data for the specific resistance of rods of different hardness inferences analogous to the above may be deduced.

(a) The specific resistance of steel increases continuously with its mechanical hardness.

(b) Rods like annealed differ but slightly, glass-hard rods considerably, with respect to their specific resistance.

(c) *Relation between the thermo-electric hardness and the specific resistance of steel.*—On comparing the values found for the ratio $\Delta S_0 / \text{T. E. H.}$, we infer that the specific resistance of steel is approximately a linear function of its thermo-electric hardness. In Fig. 30 these results are graphically represented.

I will remark, however, that the assumption of proportionality as based on the above figures is to be regarded as a first approximation

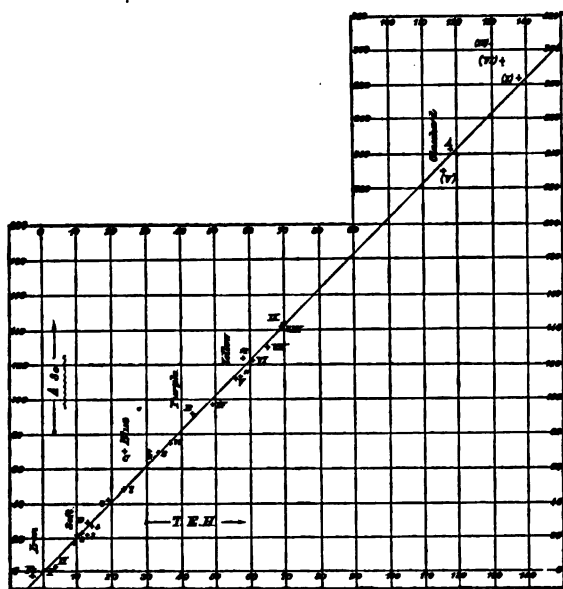


FIG. 30.—Relation between thermo-electric power and specific resistance.

only, notwithstanding the fact that the discrepancies fall within the errors of experiment. A rigid discussion of the latter comes more appropriately within the scope of another paper soon to appear. In this place I would only call attention to the following: In the thick bars

experimented upon the value of $\Delta S_0 / T$. E. H. is usually too large; a fact which is easily accounted for, as the unavoidable resistances of contact above referred to will in this case have a relatively great effect, the resistances of the bars themselves being very small. In the rods included in Table VI it was impossible to secure uniform redness of ignition throughout; the ends invariably remained darker. As T. E. H. depends principally on the warm end, ΔS_0 , however, on the mean hardness of the whole bar, we have thus a second cause for an overlarge ratio.

So much I think to have fully established, that T. E. H. and specific resistance throughout their variations are very simple functions one of another. T. E. H. and specific resistance must therefore be looked upon as effects of the same cause, as *phenomena having some very intimate connection*.

(d) Particular attention must here be called to the remarkable result, that the specific resistance of steel can by a process of glass-hardening be increased to *nearly three times* its value in soft steel.²⁰⁹ As this datum far exceeds that determined by Mousson (about 25 per cent.), it is not without some hesitation that I make it public. The care bestowed on the experiments, however, together with the regularity observed in the variation of the results, I believe sufficiently insure their correctness. See, moreover, § 6, E.²¹⁰

(e) As deserving special notice, I will further add that the thermo-current always passes from the bar with greater to the bar with less resistance.²¹¹ The few exceptions to this fact in the tables were afterwards found to be referable to errors of experiment by direct observation.

(f) Like T. E. H., so also the specific resistance of steel approximates to the value of this constant for soft iron. Upon the value found for

²⁰⁹ It is to be observed, however, that the difference between the specific resistance of steel in the soft and hard states is dependent on the composition, increasing with the quality of carbon contained from a very small value in soft iron to the very large value above announced for steel.

²¹⁰ Chwolson reports the increase of resistance due to glass-hardening to be only 0.6 per cent. This I can only explain by supposing the results of this observer to have been obtained with wires suddenly cooled at a temperature below that referred to in § 7 (c).

²¹¹ I would here again refer to the fact that, according to Magnus, Thomson, and Mousson, drawn-steel wire and hard-tempered steel are on opposite sides of soft steel, both with respect to their thermo-electric properties and their specific resistance. Thomson furthermore finds transversely magnetized steel electro-negative towards soft steel, this again towards longitudinally magnetized steel. Auerbach (Wied. Ann., V, p. 316, 1878), analogously, that the specific resistance of hard steel continuously increases as the rod passes from a condition of saturated longitudinal to a condition of saturated circular magnetization. The result above enunciated has therefore probably even a more general signification.

the ratio $\Delta S_0 / T. E. H.$, however, not much reliance can be placed, the factors involved being too small to admit of accurate determination.

With cast-iron no experiments were made.

9.—REMARKS ON THE ABOVE, CONSIDERED AS AUXILIARY TO THE DETERMINATION OF THE RELATION BETWEEN HARDNESS AND MAGNETIC MOMENT.

In this place I will avail myself of the experiments of Ruths on the relation between hardness and magnetic moment, these being perhaps the most comprehensive. With sufficient approximation for the purpose I will put the T. E. H. of glass-hard rods = $120 : 10^6$; that of the yellow annealed, = $40 : 10^6$; of the blue, = $20 : 10^6$; and with these as abscissæ and Ruths' values for the corresponding permanent magnetic moments ("in millions of absolute units," milligrammes-millimeters-seconds) as ordinates, suppose the curves belonging to each of the bars to be constructed. These curves are given in figure 31, the attached number referring to the ratio between the length and the diameter of each rod.²¹²

I will omit the interesting deductions which Ruths makes from his data, these going beyond our present purpose.

From an inspection of the curves we derive the following important results, viz: that, like the electrical properties of steel and its specific gravity, so also the maximum of permanent magnetism is largely modified by the different degrees of glass-hardness of the bar (*i. e.*, those lying above yellow annealed, and scarcely distinguishable mechanically). In the second place, the results of Ruths, being obtained from comparatively thick rods, are largely influenced by structure. In view of these facts, I deem the hope by no means too sanguine that if, to avoid complications from structure, we experiment on thin rods, the maximum of permanent magnetism may be empirically expressed in terms of the dimensions and T. E. H. only; that, furthermore, from the parallelism discovered in the variation of specific gravity and the electrical prop-

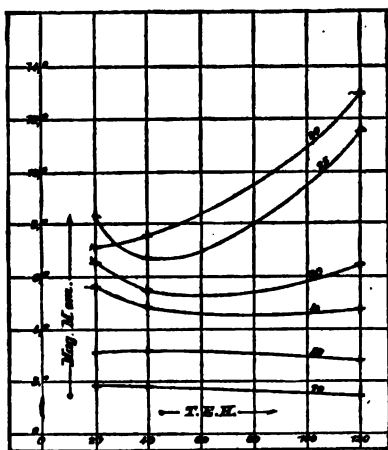


Fig. 31.—Diagram of Ruths' results.

²¹² The data employed are those obtained by Ruths for rods 120 millimeters long, and 1.7, 2.4, 2.9, 3.8, 4.9, 5.9 millimeters, respectively, in diameter, with very powerful magnetizing forces.

erties of steel, the T. E. H., the specific resistance, and the magnetic moment are in some very intimate way connected with the volume of a unit of mass. This would imply a connection of these phenomena with the intermolecular spaces of steel.

In conclusion, it gives me great pleasure to acknowledge my indebtedness to Professor Kohlraush for much kind assistance throughout the course of the experiments.

PHYSICAL INSTITUTE, UNIVERSITY OF WÜRZBURG,

February, 1879.

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BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 15

NOTES ON THE MESOZOIC AND CENOZOIC PALEONTOLOGY
OF CALIFORNIA

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

ADVERTISEMENT.

[Bulletin No. 15.]

The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

“The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States.”

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

“That whenever any document or report shall be ordered printed by Congress, there shall be printed in addition to the number in each case stated, the ‘usual number’ (1,900) of copies for binding and distribution among those entitled to receive them.”

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. iv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, and VIII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt., U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price \$10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price \$11.

IV. Comstock Mining and Minerals, by Elliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price \$1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price \$1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price \$1.05.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price \$1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 208 pp. 24 l. 24 pl. Price \$1.10.

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The following are in press, viz:

- IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. ix, 338 pp. 35 pl.
 X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 56 pl.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. —, — pp. 46 pl.

The following are in preparation, viz:

- I. The Precious Metals, by Clarence King.
 Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.
 Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.
 Lake Bonneville, by G. K. Gilbert.
 Sauroptoda, by Prof. O. C. Marsh.
 Stegosauria, by Prof. O. C. Marsh.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 14 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 43 pp. 2 pl. Price 10 cents.
2. Gold and Silver Conversion Tables, giving the coining value of Troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.
3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30', from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.
4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 26 pp. 9 pl. Price 5 cents.
5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.
6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.
7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752-1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.
8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by E. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.
9. A Report of work done in the Washington Laboratory during the fiscal year 1883-'84. F. W. Clarke, chief chemist; T. M. Chastard, assistant. 1884. 8°. 40 pp. Price 5 cents.
10. On the Cambrian Faunas of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.
11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.
12. A Crystallographic Study of the Thimolite of Lake Lahontan, by Edward S. Dana. 1884. 8°, 34 pp. 3 pl. Price 5 cents.
13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 125 pp. Price 10 cents.
14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.
15. On the Mesozoic and Cenozoic Paleontology of California, by Dr. C. A. White. 1885. 8°. 83 pp. Price 5 cents.

Numbers 1 to 6 of the Bulletins form Volume I, and numbers 7 to 14 Volume II. Volume III is not yet complete.

The following are in press, viz:

16. On the higher Devonian Faunas of Ontario County, New York, by J. M. Clarke. 1885. 8°. — pp. 3 pl. Price — cents.
17. On the Development of Crystallization, etc., by Arnold Hague and J. P. Iddings. 1885. 8°. — pp. Price — cents.
18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Dr. C. A. White. 1885. 8°. — pp. 3 pl. Price — cents.
19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. — pp. Price — cents.
20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. — pp. 1 pl. Price — cents.
21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. — pp. 5 pl. Price — cents.

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STATISTICAL PAPERS.

A fourth series of publications having special reference to the mineral resources of the United States is contemplated.

Of that series the first has been published, viz:

Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

The second volume of this series, Mineral Resources 1883 and 1884, is in preparation and will soon be put to press.

Correspondence relating to the publications of the Survey, and all remittances, which must be by POSTAL NOTE or MONEY ORDER, should be addressed

TO THE DIRECTOR OF THE

UNITED STATES GEOLOGICAL SURVEY,

Washington, D. C.

WASHINGTON, D. C., *May 5, 1885.*

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 16



WASHINGTON
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1885

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

ON

THE HIGHER DEVONIAN FAUNAS

OF

ONTARIO COUNTY NEW YORK

BY

JOHN M. CLARKE



WASHINGTON

GOVERNMENT PRINTING OFFICE

1885

LETTER OF TRANSMITTAL.

**DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., January 13, 1885.**

SIR: I have the honor to transmit herewith a paper entitled *On the Higher Devonian Faunas of Ontario County, New York*, by Mr. J. M. Clarke.

Mr. Clarke has had unusual opportunities for making a critical study of the Devonian strata and faunas of the district mentioned, and I respectfully recommend the publication of his paper in the form of a bulletin as giving valuable new data.

Very respectfully,

CHAS. D. WALCOTT,
Paleontologist.

Hon. J. W. POWELL,
Director of the United States Geological Survey.

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THE HIGHER DEVONIAN FAUNAS OF ONTARIO COUNTY, NEW YORK.

BY JOHN M. CLARKE.

INTRODUCTORY REMARKS.

The materials and the conclusions presented in this paper are the partial results of studies of the Devonian of Western New York, which have been of several years duration. Since the summer of 1877 much attention has been given to the finer subdivision of the Devonian on strictly paleontological evidence, the rich development of Devonian faunas within Ontario County, and in its vicinity, having afforded an unequalled opportunity for such work. What is here given concerns only the Higher Devonian strata and their contents, viz., those of the Genesee, Portage, and Chemung formations, and the materials here made use of have been derived principally from the county of Ontario, with important additions from the eastward and westward extension of these strata into the adjoining counties of Yates and Livingston.

In preparing these notes I have received many kindnesses from my companion in the field, Mr. D. D. Luther, esq., of Naples, N. Y., to whom credit belongs for many of the discoveries here detailed.

BIBLIOGRAPHY OF THE FORMATIONS HERE DISCUSSED, VIZ., THE GENESEE, THE NAPLES, THE PORTAGE, AND THE HIGH POINT CHEMUNG ROCKS OF THE STATE OF NEW YORK.

1839. Conrad, T. A.—Second Annual Report on the Paleontological Department of the Geological Survey of New York.

Vol. III, pp. 57-66.

1841. Conrad, T. A.—Fifth Annual Report on the Paleontological Department of the Geological Survey of New York.

Vol. V, pp. 25-57.

1842. Conrad, T. A.—“Observations on the Silurian and Devonian Systems of the U. S., with descriptions of new organic remains.”

Journal Acad. Nat. Sci. Phila., Vol. VIII, Pt. II, pp. 228-280.

1842. Vanuxem, L.—Geology of New York, Survey Third Geological District.

Pp. 166-185, 249-303.

1843. **Hall, James.**—Geology of New York, Survey of Fourth Geological District.
Pp. 217-277, 414-449.
1846. **Verneuil, E. de.**—"Note sur le parallélisme des roches des dépôts paléozoïques de l'Amérique Septentrionale avec ceux de l'Europe, suivie d'un tableau des espèces fossiles communes aux deux continents, avec l'indication des étages où elles se rencontrent, et terminée par un examen critique de chacune de ces espèces."
Bulletin de la Société Géologique de France, 2 série, Tome IV, pp. 649-710.
(Translated by Mr. Hall, and published in Am. Journal of Sci., 2d ser., Vol. V, pp. 176-183, 359-370; Vol. VI, pp. 45-51, 218-231.)
1857. **Hall, James.**—"Descriptions of Paleozoic Fossils."
In Tenth Ann. Rep. N. Y. State Cab. Nat. Hist., pp. 41-180.
1858. **Bigsby, J. J.**—"On the Paleozoic Basin of the State of New York, Part I. A synoptical view of the mineralogical and fossil characters of the Paleozoic Basin of the State of New York."
In Quar. Jour. Geol. Soc., Vol. XIV, pp. 335-427.
1858. **Bigsby, J. J.**—The same, Part II. "Classification of the Paleozoic Strata of the State of New York."
In Quar. Jour. Geol. Soc., Vol. XIV, pp. 427-452.
1859. **Bigsby, J. J.**—The same, Part III. "An inquiry into the sedimentary and other relations of the Paleozoic Rocks of the State of New York."
In Quar. Jour. Geol. Soc., Vol. XV, pp. 251-335.
1860. **Hall, James.**—"Notes and observations upon the fossils of the Goniatite Limestone, in the Marcellus shale of the Hamilton group, and those of the Goniatite Beds of Rockford, Indiana, with some analogous forms from the Hamilton group proper."
In Thirteenth Ann. Rep. N. Y. State Cab. Nat. Hist., pp. 95-112.
1862. **Dawson, J. W.**—"On the Flora of the Devonian Period in north-eastern North America."
In Quar. Jour. Geol. Soc., Vol. XVIII, pp. 296-330.
1863. **Hall, James.**—"On the occurrence of Crustacean Remains of the genera *Ceratiocaris* and *Dithyrocaris*, with a notice of some new species from the Hamilton group and Genesee slate."
In Sixteenth Ann. Rep. N. Y. State Cab. Nat. Hist., pp. 71-75.
1863. **Hall, James.**—"Descriptions of new species of Brachipods from the Upper Helderberg, Hamilton, and Chemung groups."
In Sixteenth Ann. Rep. N. Y. State Cab. Nat. Hist., pp. 19-66.
1866. **Green, H. A.**—"On a few of the Fossiliferous Localities in Livingston and Genesee Counties, New York."
In Am. Jour. Sci., 2d ser., Vol. XLI, pp. 121-122.
1867. **Hall, James.**—Paleontology of New York.
Vol. IV.

1869. **Hall, James.**—"Preliminary notice of the Lamellibranchiate shells of the Upper Helderberg, Hamilton, and Chemung groups of New York."
Pamphlet. 8vo.
1875. **Hall, James.**—"Description of new species of Goniatitidæ, with a list of previously described species."
In Twenty-seventh Ann. Rep. N. Y. State Mus. Nat. Hist., pp. 132-136.
1876. **Hall, James.**—Illustrations of Devonian fossils.
1879. **Hall, James.**—Paleontology of New York.
Vol. V, Pt. II.
1879. **Hinde, G. J.**—"On Conodonts from the Chazy and Cincinnati groups of the Cambro-Silurian, and from the Hamilton and Genesee shale divisions of the Devonian in Canada and the United States."
In Quar. Jour. Geol. Soc., Vol. XXXV, pp. 351-369.
1880. **Lesquereux, Leo.**—"Coal Flora of the Pennsylvania Coal Measures."
In Second Geol. Survey of Pa., Vol. P.
1880. **Williams, H. S.**—"Paleontological Researches."
In Science, Vol. I, No. 16, p. 190.
1880. **Williams, H. S.**—"Some Paleontological studies on the life-history of *Spirifer lævis* H."
In Proc. Am. Assoc. Adv. Sci., Vol. XXIX; and Am. Jour. Sci., 3d s., Vol. XX, pp. 456-459.
1881. **Williams, H. S.**—"The Recurrence of Faunas in the Devonian Rocks of New York."
In Proc. Am. Assoc. Adv. Sci., Vol. XXX, pp. 186-191.
1881. **Williams, H. S.**—"On fish remains from the Upper Devonian."
In Proc. Am. Assoc. Adv. Sci., Vol. XXX, p. 192.
1881. **Dawson, J. W.**—"Notes on new Erian (Devonian) plants."
In Quar. Jour. Geol. Soc., Vol. XXXVII, pp. 299-308.
1882. **Dawson, J. W.**—"Recent discoveries in the Erian Flora of the United States."
In Am. Jour. Sci., 3d s., Vol. XXIV, pp. 338-345.
1882. **Dawson, J. W.**—"Fossil plants of the Erian and Upper Silurian of Canada, Part II."
In Geol. Survey of Canada, pp. 95-133.
1882. **Williams, H. S.**—"New Crinoids from the Rocks of the Chemung Period of New York."
In Proc. Acad. Nat. Sci. Phila., pp. 17-34.
1882. **Williams, H. S.**—"Catalogue of the Fossils of the Chemung Period of North America."
1882. **Clarke, J. M.**—"New Phyllopod Crustaceans from the Devonian of Western New York."
In Am. Jour. Sci., 3d ser., Vol. XXIII, pp. 476-478.

¹ This work is introduced here as it is not altogether a compilation from other works, but contains a number of species not before recognized in these rocks.

1883. **Williams, H. S.**—"On a Remarkable Fauna at the base of the Chemung group in New York."
In Am. Jour. Sci., 3d ser., Vol. XXV, pp. 97-104.
1883. **Clarke, J. M.**—"New discoveries in Devonian Crustacea."
In Am. Jour. Sci., 3d ser., Vol. XXV, pp. 120-125.
1883. **Hall, James.**—Paleontology of New York.
Vol. V, Pt. I. Plates. (Text in part, 1884.)
1883. **Dawson, J. W.**—"On Rhizocarps in the Paleozoic Period."
In Proc. Am. Assoc. Adv. Sci., Vol. XXXII, pp. 260-264.
1884. **Williams, H. S.**—"On the Fossil Faunas of the Upper Devonian along the meridian of 76° 30', from Tompkins County, New York, to Bradford County, Pennsylvania."
In Bull. U. S. Geological Survey, No. 3.
1884. **Ringueberg, E. M. S.**—"A new Dinicthys from the Portage group of Western New York."
In Am. Jour. Sci., 3d ser., Vol. XXVII, pp. 476-478.

THE PETROGRAPHIC AND PALEONTOLOGIC CHARACTERS OF THE GENESEE BEDS.

TYPICAL EXPOSURES.

1. East and west shores of Canandaigua Lake from Seneca Point and Genundewah south to Woodville.
2. The ravines on the west side of Canandaigua Lake, viz.; at Black Point, Seneca Point, and Foster's Point.
3. Cheshire in Canandaigua Township.
4. Bristol Center in "Blacksmith's," Randall's, and other gullies.
5. Hamilton Gully, Honeye Lake.
6. Glenville, Hemlock Lake.

These shales constitute the uppermost subdivision of the rocks of the Hamilton Period, and are usually regarded as representing the uppermost Middle Devonian in New York. Since the original thorough characterization of these strata in the Geological Report of the Fourth District of New York, in 1843, their petrographical features, in a general sense, have been well known. In Ontario and the adjoining counties they are developed as a mass of bituminous shales, although varying in the amount of organic matter they contain in different horizons and localities.

Bituminous shales occur also in the overlying Naples group of strata, which are separated from the dark layers of the Genesee by a distance of only a few feet of green shales, and on this account their bituminous character does not always serve to identify their outcrops where the adjoining rocks are not exposed. The order of succession in the Genesee strata of the district under consideration is not constant, largely explained by the fact that the rocks are shales, although in the fact of their tendency to local variations these beds differ from the shales of the underlying Hamilton *properment dit* which I have found to be quite persistent in petrographical character and paleontological contents.

Along the shores of Canandaigua Lake, where the strata have an excellent development, there are at the base of the group about 20 feet of bituminous arenaceous shale, containing rows of concretions of impure calcic carbonate, this overlaid by 40 feet of densely bituminous rock having a perfect cleavage that gives it a close resemblance to a slate. This bed is so rich in organic matters that a blow of the hammer evaporates enough of the lighter hydrocarbons to produce a very strong petroleum smell. Over limited areas it loses its schistose character, becomes compact and densely rich in bituminous matter. The freshly broken surface is of a deep black or dark coffee color, and the streak chocolate brown. On account of numerous planes of jointing which

cross these layers, and the capacity of the rock for resisting weathering, they always make a marked feature in a landscape. The exposures are generally high walls covered with projecting battlements, buttresses and parallelipedons.

Above these strata lies a mass of black, fragile, clay shale, 100 feet thick, which passes into the overlying transition shales.

Further than this there is no variation in the rocks of the Genesee division in Ontario County, except in the case of the thin calcareous beds which are here designated as the *Styliola* layer.

In the summer of 1878 I received from Mr. Hall a small fragment of limestone quite made up of the exuviae of the little pteropod which had already been described by him as *Tentaculites fissurella*, subsequently as *Styliola fissurella*. The specimen had been collected in the course of the geological survey of 1837-'43 from a loose block in the town of South Bristol, Ontario County. Accompanying the specimen was a request that I should make a search for the outcrop of this rock, and subsequent searches resulted in finding the layer in the midst of the dark shales of the Genesee and about 20 feet from their base, a little to east of the village of Cheshire in the township of Canandaigua. Continued searches for the distribution of the layer have discovered its outcrops in many and widely separated localities throughout the width of the district under consideration. Wherever occurring this layer is quite unique in its composition, consisting almost wholly of the shells of these minute pteropods, which are so small that they measure no more than $1\frac{1}{2}$ to 2^{mm} in length, and so abundant that I have estimated from good specimens of the limestone at least 40,000 individuals to a cubic inch of the rock. *Styliola fissurella* occurs also in great abundance in other horizons, as in the bituminous shales of the Marcellus epoch, where it is very characteristic of the blackest and most fissile layers.² Hall has also quoted the species as occurring in great abundance in the Black Slates of Lexington, Indiana, where it is associated with *Chonetes lepida* H. Further on in this paper I note the recurrence of the fossil in great quantities in a concretionary Goniatite-bearing stratum of the Naples shales, but nowhere else does it occur in so great abundance as at this horizon.

This *Styliola* layer varies somewhat in petrographical character in its different outcrops. On the shores of Canandaigua Lake it makes a somewhat concretionary limestone about 1 foot in thickness, and with a strong schistose tendency. In the ravines about Bristol Center and further to the west its concretionary character becomes more strongly marked, and in these places the concretionary masses are overlaid and underlaid by masses of strongly bituminous shale containing the same fossil in the same abundance. Still farther west, in the township of Richmond, and near Hemlock Lake, the layer becomes pretty well sepa-

²Paleontology of N. Y., Vol. V, Pt. II, p. 179.

rated into a succession of thin, very calcareous bands, which are scattered through a thickness of several feet in the dark shales; but, however it may oscillate between shale and limestone, its place in the rocks is at once marked by the predominance of the *Styliola*. Its persistence is noteworthy, as Mr. Hall states that a similar limestone 6 inches thick is to be found on Cayuga Creek, near Alden, Erie County, about 80 miles further west.

Whether the rock of the stratum be limestone or shale, it is always extremely rich in organic matter. I find that in most of the shales there is quite as great an abundance of *Styliola* shells as in the limestone, while there is a much greater quantity of organic matter, and to this may be ascribed the more perfectly developed tendency to cleavage in the shales, for the calcium carbonate of both limestone and shales is almost wholly derived from these shells. Thin sections show under the microscope that the rock has little else in it than these exuviae, so closely crowded together that not infrequently one individual is thrust inside of another, and a third inside the second. In whatever direction of a fragment of the rock a thin slice is made, all the interspaces between the individuals which have been longitudinally cut are usually completely filled with transverse sections of other individuals, lying at varying angles to those which have happened to be longitudinally cut. Interstices too small to accommodate a *Styliola* are very often filled with bituminous matter, and it is quite common to find in the interior filling of the *Styliola* a considerable intermixture of organic matter left from the decomposition of the original tenant of the shell. The cementation of these originally loose shells has naturally been effected by percolating waters dissolving and depositing calcic carbonate. The thin sections show that this calcite has been deposited evenly on the entire inner surface of the shells, the youngest surfaces of the deposit coming together in a line, which is the longitudinal axis of the shells, giving thus to the longitudinal section the appearance of vein-infiltration. Many of the longitudinally cut individuals show also an external coating of calcite, which appears at best advantage where the original accumulation of shells has had a somewhat looser texture and plenty of room has thus been left between the shells for the deposition of such a layer. Both external and internal deposits are crystalline. Every *Styliola* shell, whether only filled with calcite or whether it has in addition to its interior filling an external coating of the mineral, shows two distinct sets of what appear at first to be twinning-lines of the rhombohedron $-\frac{1}{2}$ R. Both of these sets of lines take their origin along the central line or axis of the shell, and proceed, each obliquely backward or toward the apex of the shell, through the interior filling, the substance of the shell itself, and the external layer without interruption, and these three layers of calcite show under the polariscope perfect optical and crystalline continuity. Such twinning-lines, as they

are ordinarily developed in a crystalline limestone are seen to occur in the individual grains, one series for each grain, but the series in the adjoining grains have absolutely no relation to one another, but in the case of the *Styliola* shells and the accompanying calcite there is always a definite relation between these two sets of twinning-lines; thus the angle which they make with each other is always the same, 49° , and this angle is invariably directed toward the stoma of the shell. Here may be thus an interesting example of the twinning of twinned calcites occurring about these *Styliola* shells. I have noticed, however, that the calcite of the *Styliola* shells invariably, polarizes throughout with the same color, and I have hitherto been unable to detect any difference in the colors afforded by the adjacent lamellæ. Not infrequently is to be discerned in the *Styliolæ* a second, but very indistinct, series of lines making an angle with the lines of the first set, the angle which they make with each other along the axis of the shell being 49° as in the first set, and directed towards the apex of the shell.

The transverse sections of these shells, when made at right angles to the axis show, with crossed Nicols, a radiate-crystalline structure, the radial needles extending from the center through the exterior coating of calcite. Their appearance suggests the structure apparent in a cross-section of a Belemnite, but in the longitudinal sections there is no such evidence of their existence as is found in the Belemnite. In polarized light these transverse sections show very beautifully the dark cross accompanying spherulitic structure. I recently requested of Professor Zirkel, of Leipsic, his opinion of the nature of the double series of lines meeting at the axis in the longitudinal sections of the shell, and have been pleased to learn that he does not regard the lines as lines of twinning, but as lines of cleavage. That these lines have the most evident axial angle always directed toward the stoma of the shell, he regards due to the orientation of the calcite in its deposition, which, under similar circumstances, would be the same for given surfaces. The fact, however, that these rhombohedron cleavage lines have the same relation to the *Styliola* shell and its enveloping calcite as rhombohedron lines to a scalenohedron of calcite, prompts a query whether each one of the acicular shells may not have taken its calcite as a scalenohedron, and whether the *Styliola* shell, itself an acute suggestion of a scalenohedron may not have exercised the influence of a scalenohedron in controlling the subsequent deposition of the calcite. Upon this question the recent investigations of Brongniart,³ Sorby,⁴ and Irving⁵ into the character of the induration of ancient sandstones may have an interesting bearing.

³ Graines Fossiles. 1880.

⁴ Address before Geol. Soc., London. Quar. Jour. Geol. Soc., Vol. XXXVI, p. 62.

⁵ Am. Jour. Science, 3d ser., Vol. XXV, No. 50.

The passage from the gray calcareous shales of the Hamilton beds *proprement dit* to the black shales of the Genesee is unusually sharply defined, a fact due evidently to the close proximity of the Tully limestone (the limit between the Hamilton and Genesee, wherever it appears). This formation is lacking in New York west of the village of Bethel, in the township of Gorham, but for a distance of 10 or 15 miles west of its last appearance its influence seems marked by the clearly defined separation between the shales of the Genesee and those of the underlying Hamilton.

But with this plane of separation very clearly marked I notice three species of brachiopoda which belong strictly to the Hamilton epoch fauna, and which cannot be regarded as an element in the proper fauna of the Genesee epoch, passing a short distance from the upper limit of the Hamilton shales into the black shales. These are *Spirifera medialis*, var. *Eatoni* H.; *S. Tullia* H.; *Orthis idonea* H.

Leaving these three fossils out of consideration, it will be seen from the table appended at the close of the discussion of the fauna of the Portage group, that there are nine species common to the faunas of the Hamilton and the Genesee epochs in this district, and it is true that with the exception of the species *Chonetes lepida* and *Chonetes setigera* none of them are in any sense characteristic or abundant in the Hamilton.

REVIEW OF THE FAUNA AND FLORA OF THE GENESEE SHALES.

PISCES.

Genus POLYGNATHUS.

1. *Polygnathus dubius*.

Polygnathus dubius Hinde, G. J., Quar. Jour. Geol. Soc., Vol. XXXV, p. 362, Pl. XVI, Figs. 6-18.

This "Conodont" tooth agrees well with some of the variations of the above species. It is the only species which I have noticed in this horizon. From the upper shales of the group at Glenville, Hemlock Lake. (*Vide* description of fossils of the Naples Shales for more particulars in regard to the occurrence of these fossils.)

Genus DINICTHYS.

2. *Dinictys Newberryi*, n. sp.

(Plate I, Fig. 1.)

From the concretions in the black, bituminous, so called Huron Shale of Ohio, which is probably closely equivalent in age with the Genesee

and Naples shales of New York, Newberry described, in 1873,⁶ the above mentioned genus with two species. These two forms have introduced to our knowledge a novel sort of monstrous fishes, and the species *D. Terrelli* and *D. Hertzeri* have gained a well-deserved reputation on account of their immense size, formidable appearance, and peculiar zoölogical relations, as well as for the beauty of the specimens obtained.

Kayser has described (Zeitsch. d. deutsch. Geol. Gesell. Vol. XXXII, p. 817) a third species under the name *Diniethys* (?) *Eifelensis*, from Gerolstein.

From the concretions of the *Styliola* layer in Blacksmith Gully, at Bristol Center, I have a beautifully preserved specimen of the lower right mandible, with the right maxillary and portions of the cranial bones of an individual of this genus. The lower mandible, which is the best preserved of all of the parts taken, is just about one-half the size of the corresponding part of either of the Ohio species. In the possession of a sharp, even, knife-like cutting edge on the mandible instead of a finely-toothed cutting edge, it is more closely allied to *D. Terrelli* than to *D. Hertzeri*, but the jaw in its relative dimensions is much less stout than in *D. Terrelli*, approaching in these particulars much more closely to *D. Hertzeri*. To show these relative proportions clearly I give herewith the measurements in the two previously described species of what may be regarded the constants in the right lower mandible for comparison with those in this smaller form. In the diagrams, column A gives the length of the mandible; B, its width at a point half way from the posterior angle to the cutting edge; C, the width from the anterior end of the cutting edge to the base of the mandible; D, from the apex of the anterior prehensile tooth to its base.

	A.	B.	C.	D.
	cm.	cm.	cm.	cm.
<i>D. Terrelli</i>	56½	15	13½	21½
<i>D. Hertzeri</i>	59	12½	11½	17½
<i>D. Newberryi</i>	28½	6½	5½	8½

By reducing these dimensions to the standard of the smallest species, we have these ratios:

	A.	B.	C.	D.
<i>D. Terrelli</i>	2	2.4	2.6	2.5
<i>D. Hertzeri</i>	2.1	2.1	2.1	2.1
<i>D. Newberryi</i>	1	1	1	1

This mandible thus is not quite one-half the size of that of either of Dr. Newberry's species, but in its relative proportions it agrees quite

⁶Geological Survey of Ohio., Pal., Vols. I and II.

closely with those of *D. Hertzeri*, while *D. Terrelli*, having a greater width in proportion to its length, has a stouter jaw. In the right maxillary we have these measurements to compare with the like in *D. Terrelli*. (I have not been able to ascertain them for *D. Hertzeri*.)

	Length.	Width.
<i>D. Terrelli</i>	cm. 15½	cm. 8½
<i>D. Newberryi</i>	6½	3½

Their ratio will be:

<i>D. Terrelli</i>	2 5	2 3
<i>D. Newberryi</i>	1	1

There is thus a similar disproportion in these bones to that in the mandibles of the two species. This measurement of width for the maxillary of *D. Terrelli* does not include the triangular process on its upper posterior limb, which is wanting in *D. Newberryi*.

In the same *Styliola* layer as it outcrops on the east side of Canandaigua Lake, near Genundewah, 6 miles from the Bristol locality, I had earlier discovered a dorso-median plate belonging presumably to the same species. Its dimensions are as follows: Length, 12½^{cm} (broken); width, anteriorly, 13¾^{cm}; height of carinal process, 5^{cm}.

In the Ohio species these dimensions are in centimeters:

D. Terrelli, 65:57½:10.

D. Hertzeri, 67½:53:10.

Compared with *D. Newberryi*, their ratios are:

D. Terrelli, 5.2:4.2:2.

D. Hertzeri, 5.4:4:2.

D. Newberryi, (♂) 1:1:1.

The posterior edge of this plate in *D. Newberryi* is broken and has apparently lost 3 or 4^{cm} from its length. The smallness of the bones of *D. Newberryi* does not indicate immature growth of an individual of either of the other species. The discovery in outcrops of the same horizon, in localities separated by a distance of several miles, of bones of different individuals, all of which seem to agree with one another in their relative proportions, is at least presumptive evidence that these individuals had attained maturity and that the size of the bones given above is that of normal full growth. (Since writing the above I have received the description of A new *Diniethys* from the Portage Group of Western New York, by E. N. S. Ringueberg (Am. Jour. Sci., 3d ser., Vol. XXVII, No. 162, June, 1884, p. 476.)

Mr. Ringueberg's species is from Sturgeon Point, on Lake Erie, 20 miles below Buffalo, and was found in the black shales of the Portage Group, the specimen consisting of a somewhat fragmentary dorso-median plate. This plate agrees well, in general dimensions, with that of *D. Neuberryi*, but there is nothing in the latter like the strongly bifurcate crest represented by Mr. Ringueberg, and the species must be regarded as distinct.

Genus PALEONISCUS.

3. *Paleoniscus devonicus*, n. sp.

(Plate I, Figs. 2-6.)

(The description of this species is given with the notice of the fauna of the Naples Shales.)

A single scale of this species I have found in the shales of Glenville, Hemlock Lake, a few feet above the *Styliola* layer.

CRUSTACEA.

Genus CERATIOCARIS.

4. *Ceratiocaris longicaudus*.

Ceratiocaris longicaudus Hall, Sixteenth Ann. Rep. N. Y. State Cab.
• Nat. Hist., 1863.

The telson spines of this species occur in the concretions of the upper arenaceous layers at Whale's Back, on Canandaigua Lake.

CEPHALOPODA.

Genus GONIATITES.

5. *Goniatites complanatus*.

Goniatites complanatus Hall, Geol. N. Y., Survey Fourth Geol. Dist.

To be found occasionally in the more arenaceous layers.

6. *Goniatites discoideus*.

Goniatites discoideus Hall, Thirteenth Ann. Rep. N. Y. State Cab. Nat. Hist., 1860.

This species, which has usually been regarded as characteristic of the Marcellus shales, occurs in fine examples in the *Styliola* layer.

7. *Goniatites Patersoni*.

Goniatites Patersoni Hall, Pal. N. Y., Vol. V, Pt. II, 1879.

The concretionary portions of the *Styliola layer* on Canandaigua Lake have afforded evidence of the comparative abundance of this species, which has been hitherto regarded as diagnostic of the Portage Group.

8. *Goniatites nodifer* n. sp.

Shell umbilicate, body-whorl expanding rapidly outwards, its width at the stoma being $2\frac{1}{2}$ times that at the beginning of the volution, compressed laterally, sloping gradually to the dorsum which is rounded, widest on the inner margin where it falls away abruptly to the inner whorls. The umbilicus shows five whorls which overlap one another in such a way as to leave each preceding one exposed for about one-fifth its width. Diameter of the normal full grown shell 14^{mm} , of which the umbilicus covers 5^{mm} . *Suture*: Dorsal lobe short, lanceolate; dorsal saddles small, rounded and sloping slightly toward the umbilicus, outer lateral lobes somewhat narrower than the dorsal saddles but of the same length; lateral saddles broad, rounded, twice as long as dorsal saddles, and distinctly sloping toward the umbilicus. Inner lateral lobe short, rounded and ventral saddle small and indistinct. This suture is very similar to that of *G. planorbis* Sandb. (Versteinerungen d. Rhein. Schicht. Nass., p. 96, Pl. IX, Fig. 3), though the Nassau species is a much more umbilicate shell. The inner whorls are edged with strong nodes, which may be the protruding ends of ridges passing across the whorls. These number from 12 to 16 for each whorl, but become fainter on the younger whorls, and are hardly distinguishable on the last volution. No other marks of ornamentation are visible.

This species is a rare form occurring in the *Styliola layer* in association with *G. Patersoni* H., and as one of the Crenate goniatites stands in close sutural relations to this fossil. Its nearer allies, however, both in form, suture, and strength of umbilication, are *G. planorbis* Sandb., *G. lamellosus* Sandb., and *G. tubereulosus* d'Arch. and Verneuil.

From Genundewah, Canandaigua Lake.

It is a matter of regret to me that on account of the recent discovery of this species it has been inconvenient to prepare an illustration of it.

Genus ORTHOCERAS.

9. *Orthoceras pacator*.

Orthoceras pacator Hall, Pal. N. Y., Vol. V, Pt. II, 1879.

A single finely-preserved example from the *Styliola layer* is referred to this species, which has hitherto been regarded as confined to the shales of the Portage Group.

Genus GOMPHOCERAS.

10. *Gomphoceras manes*.*Gomphoceras Manes* Hall, Pal. N. Y., Vol. V. Pt. II, 1879.

A large fragment measuring 3 inches in diameter, probably belongs to this species. From the *Styliola* layer.

PTEROPODA.

Genus COLEOLUS.

11. *Coleolus aciculum*.*Orthoceras aciculum* Hall, Geol. N. Y., Survey Fourth Geol. Dist., 1843.*Coleolus aciculum* Hall, Pal. N. Y., Vol. V, Pt. II, 1879.

Occasionally in the lower arenaceous shales on Canandaigua Lake, and not uncommon in the *Styliola* layer.

Genus TENTACULITES.

12. *Tentaculites gracilistriatus*.*Tentaculites gracilistriatus* Hall, Pal. N. Y., Vol. V, Pt. II, 1879.

Not infrequent; associated with the following species in the calcareous layers.

Genus STYLIOLA.

13. *Styliola fissurella*.*Tentaculites fissurella* Hall, Geol. N. Y., Survey Fourth Geol. Dist., 1879.*Styliola fissurella* Hall, Pal. N. Y., Vol. V, Pt. II, 1879.

Rare, except in the calcareous layers and concretions.

GASTROPODA.

Genus PLEUROTOMARIA.

14. *Pleurotomaria Itys* var. *tenuispira*.

Pleurotomaria Itys var. *tenuispira* Hall, Pal. N. Y., Vol. V, Pt. II, 1879, Pl. XXX, F. 25.

The concretions of the *Styliola* layer afford in considerable abundance a species of *Pleurotomaria* agreeing with this variety in its strong re-

volving striæ, which are especially prominent on the upper surface of the whorls.

The original of Hall is from the Hamilton Shales of Hamburgh, N. Y.

15. *Pleurotomaria rugulata*.

Pleurotomaria rugulata Hall, Thirteenth Ann. Rep. N. Y. State Cab. Nat. Hist., 1860.

This species, which is very characteristic of the Marcellus shales, I have found in a few instances in the lower shales in Bristol Center.

Genus BELLEROPHON.

16. *Bellerophon striatus* (f).

Bellerophon striatus Ferussac and d'Orbigny. Bronn, Lethæa Geognostica, Pl. I, Fig. 11.

The concretions of the *Styliola layer* contain a *Bellerophon*, which will probably be referable to this species. This shell has a width of from 16 to 18^{mm} across the stoma, is not explanate, but has the proper proportions of *B. striatus* as given in the place cited. The younger portion of the body whorl is covered by a callous, the remainder of the volution showing an ornamentation consisting of tubercles or papillate elevations, crossing which may be seen the lamellose lines of growth. The dorsum is strongly defined, is free of tubercles, and is crossed by retrally bent lines of growth. *B. Mæra* H. (Pal. N. Y., Vol. V, Pt. II, p. 119, Pl. XXV, Figs. 9-14, and Pl. XXVI, Figs. 19-24) has a similarly tubercled surface, but the dorsum is also tubercled.

From Genundewah, Canandaigua Lake.

Bellerophon striatus occurs in rocks of approximately the same age, in the Iberg formation of the Harz Mountains.

PELECYPODA.

Genus LUNULICARDIUM.

17. *Lunulicardium fragile*.

Avicula fragilis Hall, Geol. N. Y., Survey Fourth Geol. Dist., 1843.

Lunulicardium fragile Hall, Pal. N. Y., Vol. V, Pt. I, 1883.

Very abundant in the *Styliola layer* on Canandaigua Lake in very large and finely preserved examples. Very common also in the more sandy shales of the series, generally in a flattened condition.

Genus *CARDIOLA*.18. *Cardiola retrostriata*.

(For the synonymy and further discussion of this species see remarks on the fauna of the Naples shales.)

This species, which reaches its culmination in the overlying Naples shales, occurs sparingly in the transition beds at the top and the arenaceous shales at the base of the Genesee.

BRACHIOPODA.

Genus *LEIORHYNCHUS*.19. *Leiorhynchus quadricostatus*.

Orthis quadricostata Vanuxem, Geol. N. Y., Survey Third Geol. Dist., 1842.

Atrypa quadricostata Hall, Geol. N. Y., Survey Fourth Geol. Dist., 1843.

Rhynchonella quadricostata Hall, Tenth Ann. Rep. N. Y. State Cab. Nat. Hist., 1857.

Leiorhynchus quadricostatus Hall, Thirteenth Ann. Rep. N. Y. State Cab. Nat. Hist., 1860.

Not an uncommon species; associated with *Discina Lodensis* in the more bituminous layers.

Genus *CHONETES*.20. *Chonetes lepida*.

Chonetes lepida Hall, Tenth Ann. Rep. N. Y. State Cab. Nat. Hist., 1857.

Characteristic of the Marcellus shales, and occurring but sparsely at this horizon.

21. *Chonetes setigera*.

Strophomena setigera Hall, Geol. N. Y., Survey Fourth Geol. Dist., 1843.

Chonetes setigera Hall, Tenth Ann. Rep. N. Y. State Cab. Nat. Hist., 1857.

Not common; much more abundant in the Hamilton shales below and the Chemung group above. From the *Styliola* layer.

Genus *DISCINA*.22. *Discina Lodensis*.

Orbicula Lodensis Vanuxem, Geol. N. Y., Survey Third Geol. Dist., 1842.

Discina Lodensis Hall, Pal. N. Y., Vol. IV, 1867.

Quite abundant in the higher, more bituminous strata at Seneca Point, on Canandaigua Lake, at Bristol Center, and at Glenville, on Hemlock Lake.

Genus LINGULA.

23. *Lingula spatulata*.

Lingula spatulata Vanuxem, Geol. New York, Survey Third Geol. Dist., 1842.

Extremely abundant in the *Styliola* layer in all its outcrops, passing through noticeable variation in size.

Genus CLADOCHONUS.

24. *Cladochonus* sp.

A member of this genus, whose specific relations have not been determined, occurs with some frequency in the *Styliola* layer on Canandaigua Lake.

CRINOIDEA.

Genus MELOCRINUS.

25. *Melocrinus Clarkei*.

Melocrinus Clarkei H. S. Williams, Proc. Acad. Nat. Sci., Phila., p. 31, 1882.

This species, which is the only crinoid described from the Genesee rocks, is limited, as far as my knowledge of it goes, to a very well defined horizon. The first specimens, consisting of a slab with eight individuals in a fine state of preservation, were found twelve years ago in Bell's Gully, on Canandaigua Lake, and until the summer of 1881 all efforts to find further traces of the species in the Genesee had been in vain. In that summer a single calyx was obtained from a thin calcareous layer about 10 feet above the *Styliola* layer near Seneca Point, on Canandaigua Lake, and subsequently discovered at the same distance above the *Styliola* layer in Bristol Center an exposure which showed seventeen calices in good preservation. This layer, which seems to be persistent over an area at least of some miles square, is not over an inch in thickness, and indicates that although this crinoid had encroached, apparently in great numbers, upon the bottom of the retired, quiet sea of this epoch so rich in decomposing organic matter, in a place where its environment would seem to be entirely against its successful growth, the entire plantation was soon overwhelmed, and the species did not return until the appearance of the fauna of the Naples shales.

PLANTÆ.

Genus LEPIDODENDRON.

26. *Lepidodendron primævum*.

Lepidodendron primævum Rogers, Geol. Survey, Penn., Vol. II, 1858.

This species is rarer at this horizon than in the fauna of the Naples

shales, but is occasionally to be found in the *Styliola* layer, and in the bituminous strata at Black Point, Canandaigua Lake.

27. *Lepidodendron Gaspianum*.

Lepidodendron gaspianum Dawson, Quar. Jour. Geol. Soc., Vol. XVIII, 1862.

I have no knowledge of the previous identification of this species in the rocks below the Chemung group. Dr. Dawson has identified it from the *Styliola* layer.

Genus CALAMITES.

28. *Calamites inornatus*.

Calamites inornatus Dawson, Quar. Jour. Geol. Soc., Vol. XVIII, 1862.

A single specimen of this species, 13 inches long and 3 inches wide, agrees well in its coarse, broad flutings with the original description of the species. From the very bituminous shales at Black Point, Canandaigua Lake.

Genus CLADOXYLON.

29. *Cladoxylon mirabile*.

Cladoxylon mirabile Unger, Beitr. z. Paläontologie d. Thüringer Waldes, 1856, p. 93, Pl. XII, Figs. 6, 7.

This species has been identified by Dawson (Fossil Plants of the Erian and Silurian of Canada, Pt. II, 1882, p. 126) from specimens taken from the *Styliola* layer on Canandaigua Lake. This is its first identification in America, the original having been described from the Upper Devonian at Saalfeld.

Genus CYCLOSTIGMA.

30. *Cyclostigma affine*.

Cyclostigma affine Dawson, Quar. Jour. Geol. Soc., Vol. XXXVII, 1881, p. 279, Pl. XII, Figs. 11, 12.

This species, described from specimens taken in the adjoining county of Yates, has been recognized by Dr. Dawson, also, in the *Styliola* layer of Canandaigua Lake.

Genus DADOXYLON.

31. *Dadoxylon Clarkei*.

Dadoxylon Clarkei Dawson, Fossil Plants of the Erian and Upper Silurian Formations of Canada, 1882, Pt. II, p. 124.

Described from examples from the *Styliola* layer. The specimens from which the original description has been made were comparatively small branches, measuring but an inch or two in diameter. More recently I have found examples 5 inches in diameter and nearly 3 feet in length. The abundance of this species in the *Styliola* horizon, and especially

in the large concretions in the shales immediately overlying, is very worthy of note. I have found it in every outcrop of the *Styliola* layer known to me, and at Bristol Center it occurs in great quantity and with fine preservation. It has proved itself the most abundant fossil wood of the Devonian of this district. To account for its presence we may assume the close proximity of land, perhaps wooded islands, as suggested by Dawson, or the mouth of some large continental water-course, through whose agency this drift-wood was carried out to sea. Its constant association, however, with the pelagic fossil *Styliola* leads us to believe that either it must have been carried in large quantities far out to sea, or that the little pteropods were swept in by ocean currents from deep water. The latter may be more probable, inasmuch as the character of the fauna and flora as a whole, with the lithological features of the formation, are such as to indicate a quiet, protected, and moderately shallow sea. The occurrence of the one crinoid known in the group, *Melocrinus*, has a definite bearing upon this conclusion. As far as known it appeared but at one horizon in the Genesee, and then in great numbers; migrating from its proper environment in deep waters, it encroached upon the Genesee fauna, but was soon overwhelmed by a deposit of muddy sediment, and did not appear again until toward the close of the epoch in which the Naples shales were laid down.

Genus SPORANGITES.

32. *Sporangites Huronensis*.

Sporangites Huronensis Dawson, Am. Jour. Sci., 1871, p. 257.

Specimens of these spores I have found in places in the more bituminous portions of the Genesee shales, but they are not commonly well preserved. It has been suggested by various authorities, most lately by Orton¹ for the Ohio Devonian and Subcarboniferous bituminous shales, that the bituminous matter contained in these rocks may be due in a large measure to these lycopodiaceous spores, from the permeation of the resinous matter contained by them through the containing rock. Whether or not this is the case, I have found these or similar macrospores in the Corniferous limestone in much greater abundance and in a more perfect state of preservation than in the Genesee, in a rock which is not black and can hardly be called bituminous. Dawson² has recently described from the Devonian beds of Rio Trombetos and Rio Cuará, Brazil, forms of spore-sacs which he has regarded as closely allied to the modern *Rhizocarps* represented by the genus *Salvinia*, and for these he has suggested the generic name *Protosalvinia*. The macrospores contained in these sporocarps are in all respects similar to the scattered macrospores of the Genesee and Corniferous. Evidence of enveloping

¹Source of Bituminous Matter in Ohio Black Shales, Am. Jour. Sci., 1882, p. 171.

²On *Rhizocarps* in the Paleozoic Period, Proc. Am. Ass. Adv. Sci., Vol. XXXII, 1883.

membranes or sporocarps, for these North American⁹ spores, such as are found in the Brazilian species, is not yet at hand, but in view of the similarity existing in the macrospores themselves of these different North and South American species, Dawson suggests the probability that all of these Devonian Sporangites were allied to the modern Rhizocarps.

In addition to these species, which constitute the known fauna and flora of the Genesee rocks of Ontario County, others have been described by other investigators from the outcrops of these rocks in other portions of the State. Hinde¹⁰ has described a large number of species of "Conodonts" from the Hamilton and Genesee shales of North Evans, Erie County, of which the following, in addition to the one I have already mentioned, are quoted from the Genesee:

<i>Prioniodus angulatus.</i>	<i>Polygnathus nasutus.</i>
<i>acicularis.</i>	<i>princeps</i>
<i>armatus.</i>	<i>palmatres.</i>
<i>spicatus.</i>	<i>punctatus.</i>

The following species is quoted by Vanuxem:¹¹

Lingula concentrica Vanuxem.

By Hall:¹²

Discina truncata Hall.

By Williams:¹³

Ambocælia umbonata Conrad.

By Dawson:¹⁴

Rachiopteris pinnata Dawson.

The Pyrite Fauna.—In the more fissile bituminous strata of the Genesee, occurring in both the lower and the higher layers, there are very often to be found nodules or concretions of pyrite, usually somewhat kidney-shaped, or a little flattened from lying in the shale, often made up of masses of cubic or pyritohedral crystals and not infrequently as large as one's head. To find fossils preserved in pyrite is a very common occurrence in all the Devonian strata of New York, as it is indeed in the strata of nearly every age. But these pyrite nodules of the Genesee prove to contain a fauna almost entirely of their own, and though it is an association of fossils quite in consonance with its Devonian surroundings, all the species which I have hitherto found them to contain are to be found nowhere else.¹⁵

⁹Vide for later investigations of these spores, Am. Jour. Sci., Vol. XXIX, April, 1885, pp. 284-289.

¹⁰Quar. Jour. Geo. Soc., Vol. XXXV, 1879.

¹¹Geol. N. Y., Survey Third Geol. Dist., 1842.

¹²Geol. N. Y., Survey Fourth Geol. Dist., 1843; Pal. N. Y., Vol. IV, 1867.

¹³Pal. Researches, "Science," Vol. I, No. 16, 1880.

¹⁴Quar. Jour. Geol. Soc., Vol. XVIII, 1862.

¹⁵With the exception of *Chonetes lepida* H.

I describe herewith the species I have determined, and take pains to give them names suggested by their environment, which will serve to keep them distinct as a fauna. I believe there is abundant opportunity to enlarge this fauna, and I trust this suggestion may be of value to others studying the same rocks.

Genus BEYRICHIA.

33. *Beyrichia Dagon*, n. sp.

(Plate II, Figs. 6, 7.)

This species measures $\frac{3}{4}$ mm in length and $\frac{3}{8}$ mm in its greatest width, which is posteriorly. Hinge line straight; ventral outline semi-oval, rounding somewhat abruptly on the posterior margin, bounded by a well-marked rim on both valves. Posterior third of the shell broadly tumescent, anterior extremity less so. Medially on the dorsal margin is a prominent tubercle, extending one-half the way across each valve. Surface smooth. From Bristol Center.

Genus GONIATITES.

34. *Goniatites Astarte*, n. sp.

(Plate II, Figs. 9, 10.)

Width, $1\frac{1}{2}$ mm; thickness, 1 mm. The remarkable rotundity which this relatively great thickness gives to the shell gives it a peculiar form which is not represented elsewhere in the Devonian of New York. Volutions, two or three. Widely umbilicated. Septa simple, arising from the ventral suture with a low, backward curve, bending very gradually forward to a long, slightly rounded dorso-lateral saddle, and turning thence abruptly to a sharp angular dorsal lobe. Ten or twelve septa in the first volution. Whorls depressed. Surface as far as known, smooth. This is quite an abundant form in the Bristol pyrite nodules.

Genus ORTHOCERAS.

35. *Orthoceras Stebos*, n. sp.

(Plate II, Fig. 15.)

I have but a single individual of this species, which measures $2\frac{1}{2}$ mm in length and $\frac{3}{4}$ mm in width. Surface marked by strong, evenly rounded annulated elevations, which are not always the same distance apart. These annulations and the interspaces are covered with extremely minute transverse linings, equally strong on both elevations and depressions. The shell widens somewhat abruptly at the body chamber. Septa not known.

36. *Orthoceras Mephisto*, n. sp.

(Plate III, Fig. 2.)

Shell measuring 3 mm in length and showing the body-chamber and eight air chambers. Shell smooth and evenly tapering from the body-

chamber. Septa at equal intervals. This is quite the commonest *Orthoceras* in the nodules and in its proportions suggest the Hamilton species, *O. erile* H.

37. *Orthoceras Asmodeus*, n. sp.

(Plate III, Fig. 3.)

Length 1^{mm}. A beautiful little species, presenting a form quite different from any other known Devonian *Orthoceras* in its relatively strong and evenly rounded annulations, which are marked by the finest longitudinal striations. No trace of septa visible.

Genus PLATYOSTOMA.

38. *Platystoma Belial*, n. sp.

Width of shell across the body whorl less than 1^{mm}. Very depressed, three volutions visible. Body whorl large, flattened, and subangulated. Aperture triangular. This minute shell is quite abundant at Bristol, and elsewhere, but so small that the drawings made of it have not been successful enough to justify publishing.

Genus LOXONEMA.

39. *Loxonema* (?) *Moloch*, n. sp.

This shell is much rarer than the foregoing; measures 3^{mm} in length, 1^{mm} in width across the body whorl. Whorls three or four. Its generic characters are not certain, as the forms thus far met with are internal casts.

Genus MODIOMORPHA.

40. *Modiomorpha* (?) *Chemos*, n. sp.

Length, 2^{mm}; width, 1½^{mm}. Beaks anterior, elevated over the hinge line, and apices appressed; anterior ligament pit short, posterior long, reaching nearly to posterior extremity of the shell. Surface marked by low, concentric ridges of growth.

Genus SPIRIFERA.

41. *Spirifera Belphegor*, n. sp.

(Plate III, Fig. 13.)

Ventral valve measures 6^{mm} in its greatest width and 4½^{mm} from apex to anterior margin. Beak prominent, arched and incurved over the cardinal area. Hinge line 1½^{mm} long, or one-fourth the width of the shell. From the extremities of the hinge line the margins round gradually to the lateral extremities. The surface marked by 14-16 very distinct plications, the strongest of which run almost to the apex. Medial sinus broad, measuring 1½^{mm} on the anterior margin. The cast shows that the

cardinal processes are long, extending one-third the length of the shell, and are subparallel. Dorsal valve elevated along medial fold, depressed on the lateral portions, with 10-12 elevated, radiating plications. Beak slightly elevated and closely incurved. I have only interior casts of these shells, the surface of which shows characteristic markings, which were probably also the markings of the exterior of the original test, as, wherever in any of these fossils from the pyrite the test has been preserved, it is seen to be extremely thin and delicate. Both valves are marked with the finest radiating lines, which are equally strong on the plications and sinuses. This species is the largest from these pyrite nodules, and is not common. The figure shows the ventral valve ten times enlarged, but I have not been able to obtain a satisfactory drawing of the dorsal valve.

42. *Spirifera Pluto*, n. sp.

(Plate III, Fig. 12.)

This is quite an abundant species, which differs from the foregoing in size and in several surface features. The ventral valve measures $3\frac{1}{2}$ mm in diameter and $2\frac{1}{3}$ mm from apex to anterior margin. Beak slightly arched and incurved, and the slope to the anterior margin is very gradual. Medial sinus wide, angled at the bottom and smooth, on each side being eight or nine slightly angulated plications. Cardinal area low and short, and evenly rounding on the extremities to the anterior margin. Cardinal processes long, slightly diverging, between which lies a short mesial process. Dorsal valve somewhat flatter, with a low medial fold and 5-7 radiating plications on either side of it. The surface of the shell shows no ornamentation. These shells will be discriminated from the foregoing species by their size, which varies but little.

Genus LEIORHYNCHUS.

43. *Leiorhynchus* (?) *Hecate*, n. sp.

(Plate III, Fig. 14.)

I refer to this genus the most abundant of these fossils. The shell is orbicular; width, 2 mm. Ventral valve marked with a broad central depression running from beak to anterior margin, the bottom of which is somewhat flattened and divided into two low ridges by a central shallow sulcus. On either side of the depression are to be counted five rounded plications, which become obsolete before reaching the beak. Beak elevated, ventricose, and arched over the hinge line. Area high. Dorsal valve more depressed, with a corresponding number of plications; beak depressed. On the ventral valve, cardinal processes prominent, diverging. On dorsal valve mesial process discernible. Surface free of sculpture.

Genus CHONETES.

Chonetes lepidus.*Chonetes lepidus* Hall.

I have one specimen of this species from Bristol Center, the only previously described species, to my knowledge, occurring in these concretions. This specimen measures 5^{mm} wide and 3½^{mm} long, which is about the normal size of the shell as it occurs in the Marcellus shales.

Here is, thus, a fauna which is entirely in harmony with the character of the fauna of the Hamilton group, and yet entirely discordant with the fauna of the Genesee rocks which contain it. The question of its origin and the nature of the sea in which it flourished, the reasons for its occurrence only with the pyrite segregations, and the possible effects of its environment upon it, are not easily to be determined. The extreme minuteness of the fossils enhances rather than lessens the interest attaching to them. The inclination which I had at first to regard them as only young, immature individuals of known species, was soon overcome by the thought that there are no fossils known in the group which could serve as adult forms to such embryos. On account of similarities in some features with species of the Hamilton shales, as those existing between *Spirifera Belphegor* and *S. Clintoni* H.; *S. Pluto* and *S. Tulia* H.; *Orthoceras Mephisto* and *O. exile* H.; *O. Stebos* and *O. Thoas* H. and *O. nuntium* H. There is also a temptation to assume that the fauna is an abnormal and aborted survival of the fauna of those shales. It may be very probable that such was the origin of this fauna, but in assuming that the species have been in any degree aborted by their peculiar environment, it is necessary to bear in mind the coexistence of *Chonetes lepidus* in its normal full size. The nodules of pyrite containing the fossils are not infrequently quite isolated, and yet where they have been found to be most abundant, namely, in the gullies at Bristol Center, they occur in such a manner that though they are generally quite disconnected from one another, they can be traced for some distance lying in the same horizon and at perhaps a distance of a foot or two above or below a similar layer. In some instances the pyrite may be seen extending for a distance of several feet as a continuous lenticular mass an inch in thickness.

These masses and nodules are not solid, compact pyrite, but are composed of little balls, strings, and twigs of pyrite, such forms as the concreting mineral is apt to assume, and among these lie the little fossils, all being cemented together by carbonate of lime and silica. On being digested in acid the parts become loosened and the fossils may be taken out.

I think we may interpret these phenomena thus: This little association of species, survivors of some old fauna, was peculiar to limited areas over the bottom of the shallow Genesee sea, where decomposition of organic matter was in progress on a large scale, by means of which the iron sulphate in the sea-water was generally deoxidized. Every

change of location of these areas of decomposition carried with it the little fauna until a considerable thickness of the mud of which the Genesee shales are built deposited over and about these spots. But with this hypothesis we would expect that these species would have occasionally strayed into contiguous sediments, or have become entangled by them, though as far as my observation has gone this does not seem to be the case. Further investigation and study, however, is desirable in this direction.

RESUMÉ.

Forty-three species constitute the described fauna and flora of the Genesee rocks of Ontario County. Of these forty-three, twenty-eight have been added to the list as the result of these investigations, and there still remain in my possession a number of undetermined Pelecypoda. To this list we must add twelve species identified by other authors from the State of New York (eight of which are "Conodonts," described by Hinde), and the number of known species stands at fifty-five. Eleven of these had pre-existed in the fauna of the Hamilton shales, viz.:

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|--|---|
| 1. <i>Polygnathus dubius</i> Hinde. | 7. <i>Pleurotomaria rugulata</i> Hall. |
| 2. <i>Polygnathus princeps</i> Hinde. | 8. <i>Pleurotomaria Itys</i> var. <i>tenuispira</i> Hall. |
| 3. <i>Goniatites discoideus</i> Hall. | 9. <i>Chonetes lepida</i> Hall. |
| 4. <i>Goniatites complanatus</i> Hall. | 10. <i>Chonetes setigera</i> Hall. |
| 5. <i>Styliola fissurella</i> Hall. | 11. <i>Cardiola retrostriata</i> v. Buch. |
| 6. <i>Tentaculites gracilistriatus</i> Hall. | |

The following sixteen pass into the Naples shales:

- | | |
|--|---|
| 1. <i>Polygnathus dubius</i> Hinde. | 9. <i>Styliola fissurella</i> Hall. |
| 2. <i>Prioniodus spicatus</i> Hinde. | 10. <i>Tentaculites gracilistriatus</i> Hall. |
| 3. <i>Paleoniscus Devonius</i> n. sp. | 11. <i>Lunulacardium fragile</i> Hall. |
| 4. <i>Goniatites discoideus</i> Hall. | 12. <i>Cardiola retrostriata</i> v. Buch. |
| 5. <i>Goniatites complanatus</i> Hall. | 13. <i>Melocrinus Clarkei</i> Williams. |
| 6. <i>Goniatites Patersoni</i> Hall. | 14. <i>Lepidodendron primævum</i> Rog. |
| 7. <i>Orthoceras pacator</i> Hall. | 15. <i>Lepidodendron Gasparianum</i> Dn. |
| 8. <i>Coleolus aciculum</i> Hall. | 16. <i>Cyclostigma affine</i> Dawson. |

The following eleven, making, with the "Pyrite fauna," twenty-two species, remain peculiar to it, not passing, as far as known, beyond its limits:

- | | |
|---|---|
| 1. <i>Dinicthys Newberryi</i> n. sp. | 6. <i>Lingula spatulata</i> Hall. |
| 2. <i>Ceratiocaris longicaudus</i> Hall. | 7. <i>Lingula concentrica</i> Vanuxem. |
| 3. <i>Gomphoceras manes</i> Hall. | 8. <i>Discina Lodensis</i> Vanuxem. |
| 4. <i>Bellerophon striatus</i> Ferussac
and d'Orbigny. | 9. <i>Calamites inornatus</i> Dawson. |
| 5. <i>Leiorhynchus quadricostatus</i> Van. | 10. <i>Rachiopteris pinnata</i> Dawson. |
| | 11. <i>Cladorylon mirabile</i> Unger. |

The Transition Shales.—The shales of the Genesee, properly so called, pass upward into a narrow band of strata similar to them in elastic

structure, measuring from 30 to 60 feet in thickness, and this bed I have previously¹⁶ designated as the Transition Shales, intending thereby only to characterize them as strata containing a fauna which shows a well-marked transition from that of the Genesee to that of the Naples shales. These passage beds have more than a merely local development in Ontario County, as they extend westward through the county of Livingston to the Genesee River, especially well developed as a mass of slightly arenaceous, dark shale at Woodville, on Canandaigua Lake and at Bristol Center. I have found the same at Hemlock Lake, and indeed wherever it has been possible to find a profile showing the junction of the Genesee and Naples shales. The fauna is quite sparse and is a commingling of species which in their best development are characteristic of both the overlying and underlying strata. *Lunulicardium fragile* H., a diagnostic fossil of the Genesee, is extremely abundant; *Coleolus aciculum* H., which occurs rarely in the Genesee, but is very abundant and characteristic of the Naples shales; *Cardiola retrostriata* v. Buch, of the Naples shales, *Goniatites complanatus* H., which culminates in the Naples shales; *Styliola fissurella* H., common from the base of the Hamilton to the base of the Chemung, but which culminates in the Genesee; *Pleurotomaria capillaria* H., of the Hamilton and Naples shales, and a *Pleurotomaria* of undescribed species, occurring in the Naples shales are all to be found, and this list, as far as known, constitutes the fauna of these beds. The small fauna is of such a mixed character that it cannot satisfactorily be referred to either the Genesee or the Naples shales, and yet on account of the predominance of *Lunulicardium fragile* and of the petrographical character of the beds it is better left under the Genesee epoch.¹⁷

¹⁶ Am. Jour. Sci., Vol. XXV, p. 120, 1883.

¹⁷ It is necessary here to emphasize the fact that these fossils which are to be found in any or all of the horizons of the lower, middle, and upper Middle-Devonian do not lose their diagnostic qualities for the horizons in which they culminate on account of this wide vertical distribution. That is to say, that although *Cardiola retrostriata* occurs in the Marcellus, Hamilton, and Genesee rocks, it is extremely rare at those horizons, and although *Goniatites complanatus* is to be found in the Hamilton shales, it is not a common or characteristic fossil as it is in the Naples shales. *Lunulicardium fragile* has been found in the Naples shales, but it is very rare and is diagnostic of the Genesee, where it culminates.

THE PETROGRAPHIC AND PALEONTOLOGIC CHARACTERS OF THE NAPLES BEDS.

TYPICAL EXPOSURES.

[Those showing the bituminous beds are in italics.]

1. In the town of Naples, the *Parrish*, *Caulkins*, *Clarke*, *Snyder*, *Hartranft*, *Grimes*, and *Tannery* Gullies.
2. In the town of South Bristol, the *Cook*, *Lapham*, *Marwell*, and *Walton* Gullies.
3. In the town of Bristol, the "*Blacksmith*" and *Randall* Gullies.
4. On Honeoye Lake the *Briggs* and *Hamilton* Gullies.
5. In the town of Italy, Yates County, the *Clark Gully* and *Whale's Back*, on *Canandaigua Lake*.
6. On *Cashagua Creek*, Livingston County, near the *Shaker Settlement*.
7. In the town of *Sparta*, Livingston County, on the *Delaware, Lackawanna and Western Railroad*.
8. On the *Genesee River*, below *Mount Morris*, Livingston County.

In the Report on the Geology of the Fourth District of New York, 1843, Mr. Hall described a series of shales, flags, and sandstones immediately overlying the Genesee shales, under the name of the Portage or Nunda Group, giving it this name on account of "its superior development along the banks of the Genesee River, in the district formerly included in the town of Nunda, now Portage." The term Nunda soon fell into disuse, and the Portage Group, as it has ever since been known, was subdivided into three parts, the first, at the base and immediately overlying the Genesee, the Cashagua Shale, so called "from its perfect development upon the Cashagua Creek," in Livingston County, where, according to the description, it consists of a "soft argillaceous rock of a green color, rapidly crumbling on exposure and forming a tenacious clay." At other localities the rock consisted of "a green shale, with thin flagstones and interlaminated sandy shale." The second subdivision was the Gardeau Shales and Flagstones, so called "from their great exposure along the Gardeau Reservation." The rocks here consisted of "alternations of green slaty and sandy shale with black slaty shale, and one or two thin courses of sandstone occurring in the space of 4 or 5 feet. As we ascend the arenaceous matter increases in quantity, the layers are thicker and more numerous, and the shale forms distinct alternations of black and green, often many times in succession, within the space of 50 feet. Toward the upper part the courses of sandstone become too thick for flagstones, and the shale is in thicker masses than below." The third subdivision was the Portage Sandstones, described as thick bedded sandstones, with occasional alternations of shale toward the base.

To the entire Portage group, including these three subdivisions, a thickness was ascribed of not less than 1,000 feet along the Genesee River. More recently Mr. Hall¹⁸ has written that the black slates of the Genesee are "succeeded by a green or olive slate or shale, followed by successive alternations of black and greenish shales, and alternately shales and flagstones, and finally heavy bedded sandstones with intermediate arenaceous shaly partings. The Genesee slate has been regarded as constituting beds of passage to the next formation, known as the Portage group, and this, as well as the succeeding shale, carries a few fossils, which are likewise known in the Hamilton group. The entire formation, consisting of shales and sandstones, and having a thickness of a thousand feet or more in Central New York, diminishes like other strata in a westerly direction. On the shore of Lake Erie it has become a succession of green and black shales and sandstones, with here and there a lenticular mass of heavy-bedded sandstones, with abundant concretions and not infrequently with lenticular masses of calcareous matter."

This entire Portage group is now regarded by Hall and Dana as constituting the earlier epoch of the Chemung period.

In Ontario County the entire series of Portage strata is very perfectly developed, reaching a thickness of between 800 and 1,000 feet, with many fine exposures; and from my study of its development here and in the adjoining counties of Livingston and Yates I present in what follows my evidence for regarding the Portage group, as it is now limited, as a heterogeneous combination of faunas, the earlier of which, that contained by the Cashaqua Shales, and the Gardeau Shales and Flags, belongs with the fauna of the Genesee Shales, and the later, that of the Portage sandstones, to the beginning of the Chemung period.¹⁹

The order of succession of these strata in Ontario County is as follows:

1. Soft olive green and grayish shales, with occasional thin flagstones. Thickness, from 10 to 15 feet.

2. Black, very bituminous, shales, at the base easily cleavable into large slate-like fragments, higher up much more compact and like the

¹⁸ Pal. N. Y., Vol. V, Pt. II, p. 151, 1879.

¹⁹ The term Naples Beds or Naples Shales, by which I have here proposed to designate the Cashaqua and Gardeau series, is used advisedly and in accordance with the precedent of adopting local names for formations. My unwillingness to discard historic names led me to attempt uniting the two names Cashaqua and Gardeau into Cashaqua-Gardeau Group (inasmuch as there seems no paleontological evidence here for the separation of the two), but so uncouth and unwieldy a name was suicidal, and I have substituted for it the term Naples Beds, from the town of Naples, Ontario County, where the sections are very perfect, and where the beds have been most carefully studied. The author does not mean to assume, in the absence of complete evidence, applicability for this subdivision outside of the district here discussed.

densest layers of the Genesee. Thickness, about 40 feet. This layer I have termed the Lower Black Band.

3. Alternations of greenish and drab, soft shales, with sandy shales and occasional flagstones, and with abundant spheroidal and fantastically-shaped calcareous concretions, sometimes occurring in layers, often isolated. Thickness, not less than 150 feet.

4. Black shales, in places quite bituminous; the Upper Black Band. Thickness, from 5 to 10 feet.

5. Flagstones, and at the top heavier-bedded sandstones with occasional alternations of sandy shales. Thickness, about 150 feet.

This thickness includes all the rocks, as far as it is possible to judge, which were ascribed by Mr. Hall to the Cashaqua and Gardeau subdivisions, and it is quite possible some of the strata which under his classification belonged to the Portage sandstones. It was naturally difficult to assign definite limits to these subdivisions, as they constantly vary in thickness in passing from east to west, and in a great thickness of conformable shales and sandstones it is often quite impossible to draw fixed planes of division.

This series of strata carries us to the lowest horizon of the Chemung rocks, that is, to the horizon of the first fossils which belong to the Chemung fauna. The separation of Cashaqua and Gardeau strata is not a good one petrographically, as the entire series of strata from the top of the *transition shales* to the base of the Portage Sandstones shows only a gradual, though regular, transition from the shaly sediments below to the sandstones above.

In the order of succession given, the shales included in subdivision 1 contain *Cardiola retrostriata* in great abundance, *Goniatites complanatus*, *Lunulicardium acutirostrum*, *L. ornatum*, *Cardiomorpha suborbicularis*. In subdivision 3 the softer shales contain the same species, and a large number of others. Indeed, it is here that the fossils of the group, never very abundant, have been mostly found. One may search, as Mr. Hall has said, an entire day in these rocks and find nothing or but very little, and though some species are very widely distributed and in places quite abundant, *e. g.*, those just mentioned, the entire group is to be regarded as comparatively barren of organic remains. At the beginning of these investigations only twenty-one species had been described from the Portage group, a number which is now increased to seventy-four.

The Bituminous Shales.—These beds, which occur in two fairly well defined horizons in Ontario County, as the Lower and Upper Black Bands, retain their persistence into the county of Livingston, the Upper Band being finely developed in the township of Sparta, along a cutting on the Delaware, Lackawanna and Western Railroad, and also $1\frac{1}{2}$ miles south of the Shaker Settlement on Cashaqua Creek. Further west they lose their persistency and become a series of thin beds alternating with the greenish shales and flagstones. The Lower Band has afforded but very few fossils, some undetermined ganoid scales from Snyder Gully, in Na-

ples, with *Goniatites Chemungensis* H. rar. In the same strata, at Bristol, I have found *Spathiocaris Emersoni* Clarke, and some undetermined placoderm plates. The Upper Band is somewhat richer in organic remains, and has afforded from Naples, *S. Emersoni* Clarke, *Polygnathus dubius* Hinde, *Prioniodus spicatus* Hinde, *P. erraticus* Hinde. These species of Conodonts are comparatively abundant in Naples, at the foot of Hatch Hill, where they are associated with large quantities of vegetable remains, apparently the stipes of ferns, and accompanied with very much pyrite. They also occur at Sparta, in the same horizon. At Sparta occur also the following:

Paleoniscus Devonicus, n. sp.

Acanthodes pristis, n. sp.

Lepidodendron primævum Rogers.

L. Gaspianum Dawson.

Cyclostigma affine Dawson.

Sporangites Huronensis Dawson.

Various undetermined fish remains.

The Goniatite Concretionary Layer.

This is an unusually interesting stratum, which lies at an elevation of about 150 feet above the top of the *transition shales*. It is largely calcareous, with a considerable intermixture of silica and alumina, and a freshly-broken surface shows compact, evenly-grained structure, like phthanite, gives a dark or sometimes bright red color mixed with considerable green, and passing usually at the surface into a light gray. In Parrish Gully, Naples, 60 feet above the first outcrop at its entrance, where is to be found the best exposure of the rock, the stratum which has been denuded of its overlying shales by the water of the gully-stream shows the peculiar surface of a concretionary layer, looking as though it had been kneaded, and where the shales overlie or underlie in the adjoining banks it is noticeable that they conform to this irregular surface. This concretionary tendency was so general at the time of the formation of the layer that the stratum itself is to be regarded as a concretionary mass, rather than a mass of concretions. From Parrish Gully it can be traced southward to Caulkins Gully, and on the opposite (west) side of the Naples Valley Mr. Luther has observed it in the Clarke Gully. In all of these outcrops the rock retains its characteristic color, contains considerable pyrite, but in its distribution loses somewhat of its silicious character and becomes more readily separable into the individual concretionary masses of which it is composed. The rock is extremely tough and hard to work, and plays havoc with hammers and chisels. The layer has a thickness of 8 inches or a foot, and is immediately overlain by a bed of soft shales with a thickness of 4 feet, filled with separated concretions molded into a great variety of fan-

tastic shapes, and which when broken show often the red and green tints of the layer below. These peculiarities of color and structure in these layers have not, as far as I know, been noticed elsewhere in the American Devonian, but they are very forcibly suggestive of the reddish, greenish, and grayish concretionary Kramenzelkalk of the Rhine Provinces and Westphalia. This similarity is so marked that a person familiar with both the New York and the German rocks might easily confound hand specimens without fossils, from the different countries. Especial emphasis is to be laid upon this resemblance on account of the nature of the fauna which this Naples formation contains. It is indeed insignificant in its development compared with that of the Kramenzelkalk or of the Goniaticitenschichten, but nowhere above the Marcellus shales of the lower Middle-Devonian are Goniaticites so abundant as here. This is an abundance in individuals and not in species, but nowhere in the Upper Devonian of America are Goniaticites to be regarded as abundant fossils. Here occur the species *Goniaticites Patersoni* H. (cf. *G. intumescens* Beyr.), *G. discoideus* H. (cf. *G. simplex* v. Buch), and *G. sinuosus* H., in comparatively great abundance and generally having served as nuclei for the concretionary masses. These features have a marked bearing upon the parallelism of the American and German Upper Devonian, and it seems evident that the same environment which produced in Germany the Flinz and Knotenkalk of the lower Upper-Devonian and the Kramenzelkalk of the higher Upper-Devonian produced this concretionary layer also in the upper portion of the lower Upper-Devonian in New York. Recently F. Roemer has noted (*Zeitsch. d. deutsch. geolog. Gesell.*, Vol. XXXI, p. 659) the occurrence in Lower Dunscombe, Devonshire, of a slight development of a Nierenkalk with *Goniaticites intumescens* and other fossils occurring in the fauna of the Goniaticitenschichten, a fact which bears out the supposition that we may have here in New York the remotest westward extension of the Goniaticitenschichten.

This layer contains the following fauna:

- | | |
|---|---|
| 1. <i>Goniaticites discoideus</i> Hall. | 7. <i>Tentaculites gracili striatus</i> Hall. |
| 2. <i>G. Patersoni</i> Hall. | 8. <i>Euomphalus planodiscus</i> Hall. |
| 3. <i>G. sinuosus</i> Hall. | 9. <i>Loronema Noe</i> n. sp. |
| 4. <i>Orthoceras pacator</i> Hall. | 10. <i>Platyostoma minutissima</i> n. sp. |
| 5. <i>Coleolus aciculum</i> Hall. | 11. <i>Cardiola retrostriata</i> v. Buch. |
| 6. <i>Styliola fissurella</i> Hall. | |

REVIEW OF THE FAUNA AND FLORA OF THE NAPLES BEDS.

PISCES.

"CONODONTS."

In the present state of our knowledge of these bodies it is not possible to assign them an exact position in a zoological classification. The original species early described by Pander from the Lower Silurian of Russia were regarded as the teeth of minute fishes, a conclusion which has been supported by Newberry, Hinde, and Nicholson. Similar bodies from the Lower Silurian have been regarded by Harley (Quar. Jour. Geol. Soc., Vol. XVII) as the spinous attachments of crustacean segments. Hinde, James, and, earlier, Grinnell have described allied forms from the Silurian and Middle Devonian as teeth of annelids. The microscopical study of the structure of these bodies by Hinde (Quar. Jour. Geol. Soc., Vol. XXXV) makes it probable that, as far as the species here mentioned are concerned, they are correctly referred to the Myxinoid fishes.

Genus POLYGNATHUS.

1. *Polygnathus dubius*.

Polygnathus dubius Hinde, Quar. Jour. Geol. Soc., 1879, Vol. XXXV, p. 362, Pl. XVI, Figs. 6-18.

Individuals of this species occur quite abundantly in the Upper Black Band where it outcrops on Hatch Hill, in Naples, overhanging the banks of the Naples inlet, and occasionally in the same horizon in the town of Sparta, Livingston County. They are associated with large quantities of vegetable remains, presumably the stipes of ferns, and much pyrite. My material shows forms agreeing with some of the remarkable variations of the species as figured by Hinde, but are confined to those he has designated as pectinated and fimbriated teeth. The crested variation has not as yet been observed. The individuals measure from 1 to 2^{mm} in length.

Genus PRIONIODUS.

2. *Prioniodus erraticus*.

Prioniodus erraticus Hinde, Quar. Jour. Geol. Soc., p. 359, Pl. XV, Fig. 14.

This species is marked by the comparatively greater distance between the cusps than in the former, and several individuals in my possession from Hatch Hill agree well with the description.

3. *Prioniodus spicatus*.

Prioniodus spicatus Hinde, Quar. Jour. Geol. Soc., p. 361, Pl. XVI, Figs. 1-3.

A single individual shows the strong terminal cusp extending below the base of the tooth, which characterizes the species.

These "Conodonts," although known from various horizons from the Lower Silurian to the Carboniferous, have not been before noticed from this.

Genus PALÆONISCUS.

4. *Palæoniscus Devonicus*, n. sp.

(Plate I, Figs. 2-6.)

Numerous specimens of individuals referable to this genus have been obtained from the railroad cutting through the bituminous layers in the town of Sparta. These are usually fragmentary, but one individual retains most of the body in place though the bones of the head have been displaced and scattered and the tail is somewhat crushed. The animal was originally about 13^{cm} in length. The cranial bones, which are found abundantly scattered through these layers, though not as yet found in juxtaposition, with the exception of those represented in Fig. 6, are characteristically marked by punctate incised lines which run along the greatest diameter of the bone, occasionally, as in Fig. 5, radiating from the most convex portion of the plate. It is quite probable that the plates in Fig. 6 represent the *parietals*, Figs. 4 and 5 the *frontals* or *squamosals*. Associated with these bones are many minute, shining, somewhat flattened, conical teeth, measuring $\frac{3}{4}$ -1^{mm} in length. The scales, except those on the dorsal ridge, are 1 $\frac{1}{2}$ ^{mm} long and $\frac{5}{8}$ ^{mm} wide, subrhomboidal in outline and very beautifully sculptured with strong elevated striæ, which take their origin at the upper forward angle and pass obliquely across the scale, the forward edge presenting the appearance of being strongly tucked. These elevated striæ become very much stronger at the posterior edge, and in this region, the upper portion of the scale being left free of striæ, shows strong punctate markings. These pittings are also to be seen in the furrows between the striæ on the anterior portions of the scale.

The median dorsal scales are large, spatulate in form, measuring 3 $\frac{1}{2}$ ^{mm} in width anteriorly, and narrowing backwards to 1 $\frac{1}{2}$ ^{mm}; length 4^{mm}. Surface strongly punctate. Dorsal fin, somewhat posterior. Ventral and anal fins not well preserved.

A single scale of this species I have also from the Genesee shales at Glenville, Honeoye Lake, which brings the first appearance of this species to a still lower horizon.

Scales of *Palæoniscus* have been mentioned by Hinde²⁰ from the Genesee shales of North Evans, Erie County, and Dana²¹ has noticed the oc-

²⁰ Quar. Jour. Geol. Soc., Vol. XXXV. ²¹ Manual of Geology, 3d ed., 1880, p. 275.

currence of *Palæoniscus* in the Black shales of Kentucky, a horizon which corresponds to the Genesee shales of New York, but I have no knowledge of the description of the species.

P. Deronicus is, I believe, the first species of this genus described from Devonian rocks.

Genus ACANTHODES.

5. *Acanthodes* (?) *pristis* n. sp.

I refer to this genus a specimen from the same locality as the preceding, the description of which is justified, although the specimen is fragmentary, because of the extreme scarcity of ichthyic remains in these rocks which are well enough preserved to allow of identification. The specimen consists of a large portion of the body of the fish, the head and tail being lost. The scales are very small, measuring 0.5^{mm} on the edge, square or slightly subrhomboidal in outline and one fourth as thick as wide. The adjacent edges at about two-thirds the distance from the upper surface are strongly grooved by a single deep furrow. The upper surface of the scales is smooth and slightly convex. In the character of its scales the species stands in harmony with the genus *Acanthodes*, though it is impossible to determine its generic relations definitively without knowing more of its fins and head.

Genus PRISTACANTHUS.

Pristacanthus Agassiz, Poissons Fossiles, Tom. III, p. 35, Tab. VIIa, Figs. 11, 12, 13.

This genus was founded by Agassiz to include a peculiar spine from the Stonesfield Oolite and the Calcaire de Caen, which was described under the name *P. securis*. From the original diagnosis the following are found to be distinctive features:

1. The very thin and fragile substance of the spine.
2. Absence of any ornamentation of the surface beyond a very fine granulation.
3. The serrate character of the tooth-like lateral processes, which occur only on one side of the spine.

From the upper portion of the Naples shales, near Milo, Yates County, I have a single spine which agrees with this genus in the first two particulars, but the lateral tooth-like processes are not so evenly serrate as in the original species.

It agrees, however, as far as I am aware, with no described genus so well as with *Pristacanthus*, and, in the opinion of Dr. Newberry, to whom the specimen was submitted for examination, may be safely placed under this genus.

6. *Pristacanthus vetustus*, n. sp.

(Plate I, Fig. 7.)

A fragment of a spine measuring 70^{mm} in length, 8^{mm} in width at the distal extremity. The posterior edge is somewhat broken away, but it

appears from the portion that remains uninjured that the spine tapered very gradually from base to apex.

The anterior edge bears fourteen serrations, which are stronger at the proximal edge. These have a strong backward bend, the upper edge curving evenly outward and downward and meeting the lower edge at an angle of about 60° . The lower edge meets the margin of the spine at nearly a right angle. Substance of the spine exceedingly thin, measuring scarcely 0.02mm , except at the extremities of the serrations, where it thickens to 0.5mm . The surface of the spine is smooth and almost flat, showing under a glass fine granulations or minute pustulations. This is the only example of the species I have seen, and represents the first occurrence of this genus in Paleozoic rocks.

A large number of undetermined scales and plates of fishes from the bituminous layers at the Sparta railroad cutting are in my possession.

ANNELIDA.

Genus *SCOLITHUS*.

7. *Scolithus verticalis*.

Scolithus verticalis Hall; *Fucoides verticalis* Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 242.

Scolithus verticalis Hall, 1852, Pal. N. Y., Vol. II., p. 242.

In the upper sands of the Naples shales and also in the higher sandstones of the Portage beds this fossil is quite abundant. I regard it as the tubular boring of some annelid rather than the remnant of vegetable life, as the tubes usually show evidence of having been filled from the top by sediments which, in being carried into the *cavities*, has arranged itself in successive concave layers. Such worm borings occur in various horizons in Paleozoic rocks. Mr. Hall applied the name *Scolithus verticalis* to similar tubular borings from the Medina sandstone, and as there exists no appreciable difference in the appearance of these simple tubes I use the name for the Naples shales specimens instead of retaining the doubtfully valuable generic term *Fucoides*.

CRUSTACEA.

Genus *CERATIOCARIS*.

8. *Ceratiocaris simplex*, n. sp.

(Plate II, Fig. 2.)

The fossiliferous shales immediately underlying the concretionary limestone of Parrish Gully have afforded three specimens of this species, the most clearly defined of which is shown in the figure. The carapace is somewhat oval in outline. At its anterior extremity it shows a retral

angular notch, above which is a slight prolongation in the median axis. The dorsal and ventral edges show a well-defined margin, which is somewhat thickened, giving a noticeable rim to the carapace. Carapace convex, rising more abruptly from the dorsal margin and deflected gently to the ventral edge. No ocular node visible. Length of the carapace, figured, 30^{mm}; greatest width, somewhat anteriorly, 10^{mm}.

9. *Ceratiocaris Beecheri*, n. sp.

(Plate II, Fig. 1.)

From the shales of Cashaqua Creek, Livingston County, I have one individual showing three abdominal segments and the caudal spines. These are apparently too large to refer to the foregoing species, and as I have not as yet observed the body-segments in the layers in which *C. simplex* occurs, it is necessary to regard this form a distinct species.

Of the segments here preserved the first has been somewhat detached from its neighbor and its anterior a little broken away. What remains measures 6^{mm} in width and 3-4^{mm} in length. The next segment is normal in its proportions, is 8^{mm} in length and 5 in width. The caudal plate is 4^{mm} in length and subtriangular, from the extremity of which is prolonged the strong central caudal spine. In the specimen this spine has been flattened horizontally and been given thus an apparently greater width than the lateral spines, which have been laterally compressed. The width of this spine across the proximal end is 3^{mm}, that of the left lateral spine 2^{mm}, and its length 12^{mm}. A strong medial ridge passes along the middle spine, taking its origin 1^{mm} from the edge of the caudal plate, where it is quite strong, and continuing through the entire length of the spine as far as visible. The left lateral spine also shows evidence in the external margin of such a medial ridge. The substance of the spines is very delicate, but shows the characteristic pseudo-vascular markings of these crustacea. Of the right lateral spine but a small portion remains, and the insertion of these lateral spines upon the caudal plate is not visible. The first two segments show, on account of the flattening to which they have been subjected, no trace of ornamentation except at the angles of the segments a low inconspicuous tubercle, two on the first segment and four on the second.

I take pleasure in giving to this species the name of Mr. C. E. Beecher, of the New York Geological Survey.

Genus ECHINOCARIS.

Echinocaris Whitfield, Am. Jour. Science, 3d ser., Vol. XIX, No. 109, p. 34.

This genus was erected in 1880, in the place cited, in a paper On New Forms of Fossil Crustacea from the Upper Devonian Rocks of Ohio, and was made to include a series of forms belonging to the *Ceratiocaridæ*, one of which at least (*E. armatus* H.) had been previously described

as *Ceratiocaris*. These differ from *Ceratiocaris* in the peculiar pustulose, nodose, and ridged character of the ornamentation of the carapace, the number of abdominal segments (4 known in *Echinocaris*, 5 or 6 in *Ceratiocaris*), and the spinose attachments to the latter. The author of the genus has described three species from the Erie shales of Ohio, a horizon which probably parallelizes with the Naples shales.

10. *Echinocaris* Whitfieldi, n. sp.

(Plate II, Figs. 3 and 4.)

Carapace with a straight hinge-line extending two-thirds its length, at the posterior extremity of which the margin is abruptly deflected at almost right angles. Ventral margin with a suboval curve rounding abruptly posteriorly and less so anteriorly. Rostral region somewhat produced, posterior extremity truncated. The margin on all sides marked by an elevated rim, most prominent on the ventral and dorsal portion. The surface is marked by fine tubercles, which are principally grouped about the cephalic portion. Six or seven quite strong elongate pustules mark the position of the anterior tubercle, below and behind which lie a number smaller and indefinitely scattered, with the exception of three or four, which make a vertical row behind the anterior tubercle, as shown in Fig. 3. Near the posterior dorsal angle, on the dorsal margin and at the posterior ventral angle, are three isolated single pustules. A well-marked but short ridge is found on the anterior portion running parallel with the anterior margin, and further backwards on the carapace are a few low ridges lying in the circumference of a circle, about and within which the finer sculpture is concentric. Under a glass the surface shows very fine and delicate scaly markings. The same fragment of shale which contains the carapace affords also the specimen of the caudal plate and spines shown in Fig. 4.

The telson consists of a subtriangular caudal plate, which is prolonged into a middle spine. To the underside of the plate the two lateral spines are jointed, although the left lateral spine is lost. Of the spines the middle one is the shortest and stoutest; all are marked with a slight ridge along the center, and both they and the caudal plate are covered with comparatively strong tubercles.

The carapace measures 27^{mm} in length and 16^{mm} in width.

From the shales of Hatch Hill, Naples.

Genus SPATHIOCARIS.

Spathiocaris Clarke, 1882, Am. Jour. Sci., 3d ser., Vol. XXIII, p. 477, Plate.

This genus was founded to include some crustacean shields, allied to *Discinocaris* Woodward, characterized by their oval-elliptical outline, triangular anterior rostral opening, and lack of a dorsal suture. It is very closely similar to Woodward's genus *Cardiocaris*; indeed it differs

from it only in having the posterior margin rounded instead of very faintly notched. In a later publication²² on these crustacea I gave my reasons for regarding the genus *Cardiocaris*, which was proposed subsequently to *Spathiocaris*, as in part at least identical with it. The committee, consisting of Mr. R. Etheridge, Dr. H. Woodward, and Professor T. Rupert Jones, appointed by the British Association for the Advancement of Science to report upon the classification of the Fossil Phyllopoda of the Paleozoic Rocks, have not admitted²³ the identity of the two genera, but have taken from each and placed elsewhere some of the original members of each genus, so that *Spathiocaris* is regarded by them as represented by two species, *S. Emersoni* Clarke and *S. unguina* Clarke.

The differences in the genera *Discinocaris*, *Cardiocaris*, and *Spathiocaris* are so slight that I willingly concede the rearrangement by the committee of the species described by me from the Upper Devonian of Bicken, viz., *S. (Discinocaris) congener*, *S. unguina*, *S. (Cardiocaris) Koeneni*, *Cardiocaris (Discinocaris) lata* H. Woodward. Objections have been made to the classification of any of these forms of the Discinocarida with the Crustacea. Among the earlier observers Keyserling and F. A. Roemer, and at the present Dames, Kayser, and perhaps others, have regarded them as a whole or in part as having had some organic connection with the Cephalopoda, with which they are sometimes associated. My description of the species occurring at Bicken called forth a vigorous reply from Professor Dames,²⁴ whose arguments have been sufficiently answered by subsequent writers upon the subject.²⁵

11. *Spathiocaris Emersoni*.

Spathiocaris Emersoni Clarke, Am. Jour. Sci., 3d ser., Vol. XXIII, p. 476, Plate, Figs. 1-3.

This species is the only well defined fossil known to me from this district which passes from the fauna of the Naples shales into that of the Chemung group. I have already quoted the species from the following different horizons (Am. Jour. Sci., 3d ser., Vol. XXV, p. 120):

1. In the lower black band of Bristol.
2. About 150 feet above the transition shales of the Genesee in the town of Naples.

²²Ueber deutsche oberdevonische Crustaceen, Neues Jahrbuch, 1884, Vol. I, p. 178.

²³2d Report at the Montreal meeting, September, 1884.

²⁴See also Dames in Neues Jahrbuch, 1885, Vol. I, pp. 275, 279.

²⁵See von Koenen, Neues Jahrbuch, 1884, Vol. I, pp. 45, 46.

Report of the committee, consisting of Mr. R. Etheridge, Dr. H. Woodward, and Prof. T. Rupert Jones (secretary), on the Fossil Phyllopoda of the Paleozoic Rocks. 1883, pp. 2, 3.

Jones and Woodward, Geological Mag., Dec. III, Vol. I, No. 8, pp. 348-355. 1884.

Second Report of the Committee on Fossil Phyllopoda. 1884.

A. S. Packard, jr., A Monograph of North American Phyllopod Crustacea. 1883, p. 451.

3. At approximately the same horizon in the town of Richmond.
4. In the upper black band, 540 feet above the transition shales, Naples.
5. At approximately the same horizon $1\frac{1}{2}$ miles south of the Shaker Settlement, along Cashaqua Creek, Livingston County.
6. At approximately the same horizon in the Delaware, Lackawanna and Western Railroad cutting in Sparta.
7. In the shales immediately overlying (4).
8. In the Portage sandstones at Portageville, Wyoming County.
9. In the lowest stratum of the Chemung, Naples.
10. In the sandstones of the Lower Chemung, in the town of Canadice, Ontario County.

CRUSTACEAN TRACKS. (?)

Twenty-five feet above the first outcrop of the Naples shales in Parish Gully occurs a bed of sandy gray-greenish shales which are filled with peculiar impressions unassociated with any traces of organic matter. These are usually 2 or 3 inches in length, and consist of two rows lying side by side, of little concavities, each concavity measuring 2^{mm} in diameter. They suggest the *Neritoides*, described by Richter,²⁸ from the sandy shales of the Lower Devonian of the Thuringian Forest, although they are always much shorter than the European specimens. These seem to me to be the result of the wallowing of some crustacean, such as we may assume would be made by the known crustaceans of these rocks, not as they crept along over the soft mud of the sea-bottom, but in coming to a position of rest from swimming. A slight, constant vibratory motion of the appendages would produce such impressions in the mud. These markings I have found higher in these shales, as in the Tannery Gully in Naples, but they prove to be most abundant in the lower outcrops.

CEPHALOPODA.

Genus GONIATITES.

Type of *Goniatites simplex* von Buch.

12. *Goniatites complanatus*.

Goniatites complanatus Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., 1879. Pal. N. Y., Vol. V, Pt. II, p. 455.

This species, which is very abundant and characteristic of these shales, occurs with considerable variation of size. From the thin flagstones of the upper portion of the beds I have some large individuals measuring 10^{cm} in diameter, but the usual forms in the shales are much smaller, averaging about 25^{mm} , the smallest noticed having a diameter

²⁸ Beitrag z. Paläon. d. Thuring. Wald., p. 48, Taf. III, Figs. 42-44.

of 4^{mm}. Specimens well enough preserved to show any trace of the septa are difficult to find, and I have not as yet seen any such from the soft, muddy shales. A few specimens from the sandy layers retain these septal sutures, though without showing distinctly the character of the dorsal lobe. Hall has figured one²⁷ example showing in part, the character of the septa, and my own specimens give this feature more perfectly. There is a marked similarity in the character of these sutures and those of *G. lamed* Sandberger,²⁸ of the Cypridinen-Schiefer and Goniaticen-Schichten. In the variety *rugosus* (Fig. 4) which is probably the young of some species like *G. intumescens*, the curves of the suture are quite the same. In the var. *complanatus* (Fig. 5) the lateral saddle is somewhat stronger, and the distance between successive sutures greater than in *G. complanatus* H. In this variety, however, there is a noteworthy agreement in the form of the shell itself.

13. *Goniatices discoideus*.

Goniatices discoideus Hall, 1860, Thirteenth Ann. Rep. N. Y. State Cab. Nat. Hist., p. 97, Figs. 3-6, 1879; Pal. N. Y., Vol. V, Pt. II, p. 441.

This species, which has hitherto been regarded as characteristic of the Marcellus shales, I have found in the concretionary limestone of Parrish Gully, Naples, and in the calcareous concretions on Honeoye Lake. It is a form in every respect comparable to *G. retrorsus* (= *G. simplex* v. Buch), as figured by Sandberger,²⁹ and Keyserling,³⁰ in the character of the sutures, the non-umbilicated shell, and the nature of the surface markings.

14. *Goniatices uniaugularis*.

Goniatices uniaugularis Conrad, 1842, Jour. Acad. Natural Science, Vol. VIII, p. 268, Pl. XVI, Fig. 4. 1879, Pal. N. Y., Vol. V, Pt. II, p. 444, Pl. LXXI, Fig. 14.

A species which presents a little variation from the foregoing in its sutures, and which is quoted by Hall from the Portage; I have, however, seen no examples of it from Ontario County.

Type of *Goniatices intumescens* Beyrich.

15. *Goniatices Patersoni*.

Goniatices Patersoni Hall, 1860, Thirteenth Ann. Rep. N. Y. State Cab. Nat. Hist., p. 99, Figs. 9-10; 1879, Pal. N. Y., Vol. V, Pt. II, p. 464.

A somewhat abundant species in the concretionary layer of Parrish Gully and in the immediately overlying and underlying shales. I very

²⁷ Pal., N. Y., Vol. V, Pt. II, Pl. X, Fig. 8.

²⁸ Verstein. d. Rhein. Schichten Syst. in Nassau, 1850-'56, p. 90, Pl. VIII, Figs. 4-9.

²⁹ Loc. cit. Pl. X, Fig. 15.

³⁰ Eine Reise in das Petschoraland, 1846, Pl. XII, Fig. 5.

much doubt the advisability of retaining this specific name, as I am unable to distinguish any differences between this species and *Goniatites intumescens* Beyr., the most abundant Goniatite in the Upper Devonian of Germany. A study of a large number of these American and European forms leads me to believe that whatever variation there may be in *G. Patersoni* from the typical forms of *G. intumescens* as figured by the brothers Sandberger,²¹ which indeed is very slight, there is a far wider variation among the forms which are in Europe referred to this species.

(Cf. *loc. cit.*, Pl. VII, Fig. 3. Roemer's *Lethæa Palæozoica*, 1876, Pl. XXXV, Fig. 10.)

This similarity lies not alone in the character of the suture as shown above, but also in the amount of umbilication and in the caliber of the shell. The form from the Naples shales is never so carinate as in some of the European varieties, but agrees perfectly with the typical forms of the species.

16. *Goniatites bicostatus*.

Goniatites bicostatus Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 246; 1879, Pal. N. Y., Vol. V, Pt. II, p. 450.

This species was referred by Ferd. Roemer and De Verneuil (*vide* Sandberger, *op. cit.*, p. 101) to *G. retrorsus* v. Buch. Mr. Hall (Pal. N. Y., Vol. V, Pt. II, p. 453) has noticed the similarity between *G. bicostatus* and some of Sandberger's varieties, as follows: "In the manner of its septa it is very closely similar to the variety *lingua*" (*G. simplex* v. Buch, Kayser²²) "and variety *typus*" (the same) "of that species, while the variety *undulatus*" (*G. undulatus* Sandb., Kays.) "represents the surface markings and the revolving carinæ." This is a rare species in the Naples shales.

17. *Goniatites sinuosus*.

Goniatites sinuosus Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 244; Pal. N. Y., Vol. V., Pt. II, p. 460, Pl. LXX, Figs. 13-15, Pl. LXXII, Fig. 11; Pl. LXXIV, Fig. 11.

Goniatites (Olymenia?) Nundaia Hall, 1875, Twenty-seventh Ann. Rep. N. Y. State Mus. Nat. Hist.

In the closer parallelism of its sutures and the sinuous sculpture of the surface this species differs from *G. Patersoni*. In its other features it is quite closely allied to it, and is not infrequently associated with it. Occurs not uncommonly in the concretionary layer of Parrish Gully.

²¹ *Loc. cit.*, Pl. VII, Figs. 1 and 2.

²² *Zeitsch. d. deutsch. geol. Gesell.*, Vol. XXV, p. 690, 1872.

18. *Goniatites Lutheri*, n. sp.

(Plate II, Fig. 8.)

Shell widely umbilicated, more so than any species with which it is associated, not excepting *G. complanatus*. Septa numerous and closely appressed, the individual figured having thirty-eight in the last whorl. The sutures are characterized by their very acute lobes and saddles. Ventral saddle very small, short and very slightly rounded, the two lateral lobes strong and acute. The lateral saddle very strong and acute, with its sides somewhat rounding. The dorsal saddle well defined and rounded, with a slight sharp carinal lobe. In the figured example the carinal portion of the shell has been somewhat folded upward, giving an abnormally thick margin to the shell. The septa are so closely crowded together that they are very nearly parallel to each other except at the apices of the lateral saddles, where the distance between them is somewhat greater than elsewhere. Surface markings are shown in some of the examples preserved in pyrite as finely incised, equidistant lines, curving gently forward over the lateral portions of the shell and more strongly forward as they near the dorsal surface. This is a very graceful species and quite distinct from any known forms belonging to the type of *G. intumescens*. Most closely allied to it is *G. forcipifer* Sandberger,³³ the closely oppressed septa of which suggest *G. Lutheri*, but there is a difference that is very marked in the acute lateral saddle and ventral lobe. This species I have seen in a few examples from the shales which overlie the concretionary limestone of Parrish Gully, and from Honeoye Lake.

19. *Goniatites peracutus*.

Goniatites peracutus Hall, 1879, Pal. N. Y., Vol. V, Pt. II, p. 463, Pl. LXIX, Fig. 8.

Suture characterized by the presence of but two instead of three saddles, as with other species of the group of *intumescens*-like forms. The dorsal saddle is also very acute. The species has been described from a fragment of the outer volution, and is "from the Portage or Lower Chemung, at Ithaca, N. Y." I do not know the species from Ontario County.

20. *Goniatites complanatus*, var. *perlatus*.

Goniatites complanatus, var. *perlatus*, 1874, Descriptions of New Species of Goniatitidae, p. 1, Hall, 1879, Pal. N. Y., Vol. V, Pt. II, p. 458, Pl. LXX, Fig. 12.

This form varies from the original species in the greater distance of the septa from each other. Hall's example is "from the lower beds of the Portage group at Homer, Courtland County, New York." I am not sure that I have seen specimens referable to this variety.

³³ *Op. cit.*, p. 82, Pl. VI, Fig. 3.

Type of *Goniatites clavilobus* Sandberger.

21. *Goniatites Chemungensis*. Variety.

Goniatites Chemungensis Hall, 1879, Pal. N. Y., Vol. V, Pt. II.

I have a single specimen from the very bituminous layers of the lower black band, in Snyder's Gully, Naples, which is the only determinable fossil, with the exception of *Spathiocaris Emersoni*, that has been found in these rocks. In its tuberculated whorls the specimen agrees with *G. Chemungensis*, but differs from Mr. Hall's description of that species in the greater number of these marginal tuberculations on each edge of the whorls. It does not agree well with the var. *aequicos-tatus* Hall, and I do not attempt any further identification of it.

Genus ORTHOCERAS.

22. *Orthoceras pacator*.

Orthoceras pacator Hall, 1879, Pal. N. Y., Vol. V, Pt. II, p. 307, Pl. LXXXIX, Fig. 16.

The flattened condition in which this species is usually found in the fossiliferous shales has not allowed any evidence as yet of the position of its siphon. It is by no means an uncommon fossil.

23. *Orthoceras aciculoides*, n. sp.

(Plate II, Fig. 11.)

Shell small, sides almost parallel. The specimen from which the figure has been made is 10^{mm} long and 1^{mm} wide. It shows six septa which are remarkable for their unusual distance from one another. The first of the air-chambers measures 2^{mm} in length, the second 2½^{mm}, the third 2½^{mm}, the fourth 3^{mm}, the fifth 3½^{mm}, the sixth is partially broken away. Siphuncle and surface sculpture unknown. This little species is quite distinct from any member of this genus in the Devonian fauna. Many of the individuals which had usually been referred to the species *Orthoceras aciculum* Hall, 1843, and which show very plainly such distant septa and subparallel sides, may be, since the erection of that species by its author into *Coleolus aciculum*, referred to *O. aciculoides*. The specimen figured is from the lower shales of Cashaqua Creek.

24. *Orthoceras Ontario*, n. sp.

(Plate III, Fig. 1.)

This is a representative of the annulated *Orthocerata*, in which the annulations are relatively distant and consist of very narrow, low, and acutely angled elevations. The distance between them increases with slight irregularities from apex to stoma, and the shell, which measures 14^{cm} in length, bears thirty of them. These rings slope abruptly to the surface of the shell, making the interspaces generally quite flat.

In these interspaces where the surface has been best preserved there is a fine sculpture of the test visible, consisting of minute, microscopic, longitudinal striations. Septa evenly transverse and regularly concentric. Siphon simple, central. The original of the species was taken from the concretionary shales in Parrish Gully, Naples, is preserved in crystalline calcite, and its form is thus retained without the distortion which usually occurs in the *Orthoceras* from these shales. As yet I know of but this specimen. The longitudinal ridge represented in the figure is a line of the attached matrix, which has been made too prominent by the artist.

25. *Orthoceras flosum*, n. sp.

(Plate II, Figs. 12, 13, 14.)

Conf. Orthoceras anguis Hall, Pal. N. Y., Vol. V, Pt. II, p. 312, PL LXXXIX, Fig. 9.

Shell tapering rapidly from stoma to apex. Test very thin and covered with finely incised lines from $\frac{1}{4}$ to $1\frac{1}{2}$ mm apart. The nature of this sculpture is such that the surface of the shell is given an imbricate appearance. These lines pass about the shell in long, low undulations, which are not parallel to the outline of the stoma. The septa and siphon have not yet been noticed. This *Orthoceras* is interesting as the only representatives in the Devonian to my knowledge of a group after the type of *O. socium* Barrande, the forms quite characteristic of the Etage E.

The peculiarity of the entire group is the thin test, undulating and imbricating concentric lines of surface sculpture, with no longitudinal markings. I have before me several examples of this species, one from Parrish Gully, Naples, one from Hatch Hill, one from Briggs' Gully, Honeoye Lake.

GASTROPODA.

Genus *BELLEROPHON*.

26. *Bellerophon natator*.

Bellerophon expansus? Sowerby, Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 244.

Phragmostoma natator Hall, 1862, Dec. new species of Fossils (Fifteenth Ann. Rep. N. Y. State Cab. Nat. Hist.); 1876, Illustrations Dev. Fossils; not *Phragmostoma natator* Hall, 1862, Fifteenth Ann. Rep. N. Y. State Cab. Nat. Hist., explanation of plate.

Bellerophon natator Hall, 1879, Pal. N. Y., Vol. V, Pt. II, p. 108.

Much confusion exists in regard to both the synonymy and the identity of this species. The original example consisted of a portion of the outer volution of the shell from the Portage (Naples) group, which was identified by Hall in 1843 as *Bellerophon expansus*? Sowerby. Subsequently, in the Fifteenth Annual Report to the Regents on the Condition of the

State Cabinets, the species was regarded as the representative of another genus on account of the supposed evidence of a transverse septum within the body whorl, and was referred to the genus *Phragmostoma* (Hall, 1861, Fourteenth Ann. Rep. N. Y. State Cab. Nat. Hist.) as *P. natator*. To this description illustrations were accidentally appended of *P. cymbula* H., of the Hudson River group (*vide* Pal. N. Y., Vol. V. Pt. II, p. 108). In the final review and description of the species, it is removed from the genus *Phragmostoma* on account of unsatisfactory evidence of the existence of the transverse septum and relegated to the genus *Bellerophon*. In this connection Hall states that the original specimen from the Portage, upon which the species was founded, was not accessible to him, and the species as illustrated by him in the Illus. of Dev. Fossils, 1876, and in Pal. N. Y., 1879, is from a fragment out of the Hamilton shales. We infer, therefore, that examples of this species which have come into the possession of the State survey have been not only rare but very poorly preserved. I have found many individuals in a very perfect state of preservation which agree, as far as may be, with Mr. Hall's description of this species. As the description of the species has been from fragmentary specimens, it is difficult for me to pronounce definitely on the identity of the very abundant examples of my own with those of Mr. Hall, but the probabilities are quite in favor of it, as I find a close agreement between the description, as far as it goes, and my specimens. Hall, in the final report on the Devonian Gastropoda, has also described a more perfect example of the genus, very similar in its features, as shown both in the illustration, Plate XXVI, Fig. 14, and in the description to *B. natator*, which he has called *B. explanatus*. This is from an uncertain horizon, probably that of the Hamilton shales, and it may be represented among the specimens from the Naples shales, but on account of its greater size and more explanate stoma, it is necessary to regard the majority of the *Bellerophona* of these shales as *B. natator*, a species common in all the outcrops of the lower fossiliferous beds.

27. *Bellerophon incisus*, n. sp.

Among my specimens of this genus from Parish Gully in Naples I find one which is distinctly different from the described species in these particulars: Fine, distant, incised, revolving lines appear on the shell at the beginning of the last volution, and pass outward, being nearly parallel for most of the distance, and become obsolete only near the margin of the shell. The dorsum is well marked from the stoma to the most elevated portion of the whorl, where it becomes obsolete. The dorsum is quite smooth, showing no trace of the retrally curving lines of growth. On either side of the dorsum on the most elevated portion of the shell are from thirteen to fifteen of the incised lines. Edge of stoma somewhat emarginate at the dorsum. No concentric striae, but a few low, irregular concentric ridges. In its general proportions the species resembles *B. explanatus* H.

Genus EUOMPHALUS.

28. *Euomphalus planodiscus*.

Euomphalus planodiscus Hall, 1860, Thirteenth Ann. Rep. N. Y. State Cab. Nat. Hist., p. 109; 1879, Pal. N. Y., Vol. V, Pt. II, p. 57, Pl. XVI, Figs. 1-4.

This species was described from the Marcellus shales, and has hitherto been regarded as limited to that horizon. I have found it to be quite common in the calcareous concretions of Briggs' Gully.

Genus PLEUROTOMARIA.

29. *Pleurotomaria capillaria*.

Pleurotomaria capillaria Conrad, 1842, Jour. Acad. Nat. Sci., Vol. VIII, p. 271, Pl. XVI, Fig. 11; 1879, Pal. N. Y., Vol. V, Pt. II, p. 77, Pl. XX, Figs. 18-21.

This species constitutes a prominent member of the gastropod fauna of the Hamilton shales, and it has been found in several examples by Mr. Luther in the Naples shales. I do not know of its occurrence in the Genesee shales except in the upper portion or transition beds. Thence it ranges upward through the lower fossiliferous beds of the Naples shales and into the flag-stones of the higher strata.

Genus TROCHUS.

Subgenus PALÆOTROCHUS.

Trochus subgenus *Palæotrochus* Hall, 1879, Pal. N. Y., Vol. V, Pt. II, p. 133, Pl. XXX, Fig. 14.

"Shell conical, trochiform; spire elevated; volutions moderately convex; aperture transverse; columella?"

The above name was proposed to include a single species, *Pleurotomaria Kearneyi* Hall, from the Upper Helderberg, of which Mr. Hall has said: "I see no reasons why it should not be embraced in the Linnean genus *Trochus* and have proposed for it the subgeneric name."

From the shales at Naples I have several specimens which agree in all but a single particular with the species described by d'Archiac and de Verneuil as *Monodonta purpurea*. (*Littorina purpurea* Sandberger) from Paffrath. In general contour, sculpture, form of the stoma, and excavation of the inner lip, they are similar, but the European species bears upon the inner lip a strong callosity which does not appear in my specimens. Although there is a wide difference in the external features of *P. Kearneyi* and my examples, there is a close agreement in all generic features. With *Ptychomphalus* and *Portlockia* of de Koninck it agrees in the form of its stoma and inner lip, but it has not in common with these genera anything that can be regarded as a *Pleurotomaria* band. Although agreeing well with *Paleotrochus*, it is difficult to point

out a singular particular in which it does not coincide with living representatives of the genus *Trochus*.

30. *Trochus* (*Pseotrochus*) *præcursor*, n. sp.

(Plate III, Figs. 6-9.)

Volutions, five. The last whorl making three-fourths the height of the shell. Distance from apex to stoma, 13^{mm}; width across the body-whorl, 13^{mm}. Whorls ventricose, depressed at the sutures. Body-whorl depressed below, with a tubercled carina passing about it two-thirds the distance from the suture. Stoma transverse, subtriangular. Outer lip simple. Inner lip without callosity. Columella with a spirally-striated excavated band, which becomes obsolete as it passes downward. Surface marked by prominent tubercles arranged regularly in spiral lines. Of these lines of tubercles, two at or near the carina are the most strongly developed, and the interval between them greater than that between any other two lines. Of these spiral rows on the body-whorl generally eight are above and seven below the carina, and are increased by intercalation. The interspaces between the tubercles show very fine, transverse linings, only to be seen with a glass.

Genus *PLATYOSTOMA*.

31. *Platyostoma* (?) *minutissimum*, n. sp.

I find in the concretionary layers in Parrish Gully and along Honeoye Lake a remarkable abundance of a minute shell which I temporarily refer to this genus. These measure across the body-whorl from $\frac{1}{2}$ to 1^{mm} and are $\frac{3}{4}$ ^{mm} high. The volutions are three in number, the last very large and ventricose; surface without any visible ornamentation. That this is the young of some gastropod is quite possible, but as there is no species of gastropod that I know from this horizon of which this could be the young form, I venture to regard it as a new species. The individuals are so abundant in places that one may count scores over a single square inch of the surface of the rock. The sections of the rock for the microscope usually give abundant evidence of them.

Genus *LOXONEMA*.

32. *Loxonema* *Noe*, n. sp.

(Plate III. Fig. 10.)

Among the specimens from the concretions of Briggs' Gully and Parrish Gully and occasionally from the soft underlying shales, is a small *Loxonema* measuring from 5 to 8^{mm} in length. This is the only representative of the genus I know from this horizon, and it is quite distinct from the *Loxonemas* of the Hamilton and Chemung faunas in the proportionally large and few ribs on the whorls.

PTEROPODA.

Genus HYOLITHES.

33. *Hyolithes Neapolis*, n. sp.

(Plate III, Figs. 4 and 5.)

Length of the shell on dorsal side, 23^{mm}; width across stoma, 8^{mm}; ventral side, $\frac{1}{2}$ to 1^{mm} longer than the dorsal, projecting above the dorsal margin of the stoma; dorsal side often showing two depressed furrows passing from apex to stoma, which are usually much increased in strength by compression. Also marked by strong transverse striations, which are especially prominent on the central, most convex portion of the shell, where they become strong *rugæ*. Toward the margins these markings become obsolete. No longitudinal sculpture. The ventral margin of the stoma is rounded, and the surface of the ventral side is marked by concentric transverse lines of growth all running parallel to the stoma. No longitudinal markings. This is a very handsome species, distinct from the species of *Hyolithes* in the adjoining faunas of the Chemung and Hamilton in the character of its sculpture. It occurs, as far as known only in the softer, lower shales. From the black shales of the upper black band in Parrish Gully I have two fragments, which bear, one a dorsal valve and one a ventral valve of a very small individual, measuring 4 $\frac{1}{2}$ ^{mm} in length, which lack the characteristic sculpture of *H. Neapolis* and belong probably to another species, although the condition of their preservation is not such as to allow their description.

Genus COLEOLUS.

34. *Coleolus aciculum*.

Orthoceras aciculum Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 243.

Coleolus aciculum Hall, 1879, Pal. N. Y., Vol. V, Pt. II, p. 187.

Abundant everywhere throughout the lower shales, associated with *Goniatites complanatus* and *Cardiola retrostriata*. I have had occasion to doubt somewhat the value of Hall's reference of this, originally regarded as an *Orthoceras*, to this genus. I have not infrequently collected specimens showing evidence of septa, these especially common in the concretions of Honeoye Lake, and which in external peculiarities agree very perfectly with the description of *Coleolus aciculum*. I have not seen the siphuncle to any of these individuals, and it may be pos-

sible that this genus includes septiferous forms. Though this does not appear from the diagnosis of it, the original figure of *Orthoceras aciculum* in the Report on the Fourth District of New York shows the presence of septa, and, as the genus stands now, may be regarded as representing a specimen of my species *O. aciculoides*. As I have already remarked, under the description of that species, many of the forms occurring in the Naples shales which have usually been referred to *O. aciculum* may have to be referred to *O. aciculoides*, and other septa-bearing forms must remain for the present without definite reference, as material is not at hand for study.

Genus STYLIOLA.

35. *Styliola (Styliolina) fissurella*.

Tentaculites fissurella Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist.; not *T. fissurella* Hall, Ills. Dev. Fossils, Pl. XXV, Figs. 12-14.
Styliola fissurella Hall, 1879, Pal. N. Y., Vol. V, Pt. II.

As already noticed, this minute pteropod is very abundant in the Naples shales, making a very large element of the calcareous matter of the Parrish Gully concretionary layer. In the shaly layers it is much less abundant, but will be found in many of the higher sandy shales and flagstones.

Karpinsky (Die fossilen Pteropoden am Ostabhange des Urals—Mém. de l'Acad. St. Petersburg, 7th ser., T. XXXII, No. 1, 1884) has suggested the probability that the paleozoic *Styliolæ* are generically different from the living members of the genus, and proposes the name *Styliolina* for the former. *Styliolina* is distinguished from *Styliola* by the form of the embryonal bulb, the lack of longitudinal furrows and thorn-like processes about the stoma, and the presence of longitudinal incised lines.

Genus TENTACULITES.

36. *Tentaculites gracilistriatus*.

Tentaculites fissurella Hall, 1876, Illus. Devonian Fossils; not *T. fissurella* Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist.
Tentaculites gracilistriatus Hall, 1879, Pal. N. Y., Vol. V, Pt. II, p. 173, Pl. XXXI, Figs. 12, 13; Pl. XXXI A, Figs. 37-47.

This species, quoted by its author from the Marcellus and Hamilton shales, I have found not uncommonly associated with the foregoing.

Tentaculites gracilistriatus is regarded by Karpinsky in the work cited above as a synonym for *T. acuaris* Richter.

PELECYPODA.

Genus CARDIOLA.

37. *Cardiola retrostriata*.

Cardiola retrostriata von Buch.

Venericardium retrostriatum von Buch. Ueber die Ammoniten, p. 50.

Cardium palmatum Goldfuss, Petrefacta-Germaniæ, p. 270, Pl. XXXIII, Figs. 8-10.

Cardiola retrostriata Keyserling, 1846, Eine Reise in das Petschoraland, p. 254, Pl. XI, Fig. 3.

Avicula speciosa Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist.

Cardiola speciosa Hall, Miller, 1877, Am. Pal. Fossils, p. 186.

Cardiola speciosa Hall, 1883, Pal. N. Y., Vol. V, Pt. I; Plates and Explanations, Pl. LXX, Figs. 2-9.

Mr. Hall described and figured in 1843 (*loc. cit.*) the species *Avicula speciosa*, and has more fully illustrated the same under the name *Cardiola speciosa* in his late work, Plates and Explanations of the Devonian Lamellibranchs of the State of New York, the entire text of which has not appeared at the present writing. There is much variation in the form of this species, as it occurs in the Naples shales. It is here the most abundant fossil in the group (excepting *Styliola fissurella*), and the hundreds of specimens which have passed through my hands show the nature of the variation to be thus: The outline of the shell is most commonly approximately circular, sometimes becoming transverse. In the circular forms the shell is more elevated at the beak than in the more transverse individuals. The variation in this respect is, however, slight, and only to be perceived in specimens from the calcareous concretions, where the form has been well preserved. The variation in size is from 2 to 8^{mm} in length in the commonly occurring individuals, averaging about 5^{mm}. The surface is marked in the normal form by eight or nine ribs, between which lie comparatively deep *sulci*. Rarely the ribs become as many as twelve or fifteen. They are crossed by closely oppressed, retrally-bent lines, in which the retral bend is sometimes an even arc, and sometimes sharply angulated at the middle. Not infrequently each of these ribs is bordered by a fine elevated margin, which limits the ends of the retral striæ. Many of these features are very well brought out in Hall's illustrations of *Cardiola speciosa* in the place cited, but he has not noticed the forms with the elevated margin to the ribs. I have compared *C. speciosa* Hall, with specimens of *C. retrostriata*, v. Buch, from the Middle and Upper Devonian of Altenau, Bicken, Adorf, Bredelar, and elsewhere, and to my mind there is *absolutely* no specific difference in the American and European species.

The European species varies within even wider limits than the American, as is well shown in the illustrations given by the Sandbergers,³⁴ where the three varieties represented do not any of them compare favorably with the most common American forms. By an error (*op. cit.*, p. 270) the variety there mentioned as *Cardiola retrostriata* var. *typus*, represents var. *augulifera*, and no illustration of the typical form is given. This *typical* form, that is, the one most usually occurring in the Upper Devonian horizons, is well illustrated by Goldfuss (*loc. cit.*), Keyserling (*loc. cit.*), and Roemer.³⁵ This form bears from eight to ten, sometimes twelve, ribs, and its sculpture is the same as in *C. speciosa*. F. A. Roemer³⁶ has given a figure of *Cardium palmatum* Goldfuss, which is rather more transverse than the usual American forms, and bears twelve ribs; this transverse form is, however to be found in the Naples shales associated with the others. *Cardiola retrostriata* v. Buch is a shell of very wide distribution throughout the Upper and Middle Devonian of Europe. Keyserling³⁷ has described it from the Domanik Schiefer of Petschora Land; F. A. Roemer³⁸ from the same horizon (Mittel Oberdevon, "Domanik Schiefer" Credner, 1883) of Altenau in the Ober Harz. It is everywhere abundant in the same horizon throughout Westphalia, in the Fichtel Gebirge, etc. In the north of France and on the Belgian frontier the "Schistes à Cardium palmatum" are a member of the Upper Devonian, and are assigned the following position by Gosselet³⁹ in the classification of the Upper Devonian beds.

Psammites du Condroz, Calcaire d'Etraëungt Psammites.

Schistes de Famenne	{	Schistes de Famenne, proprement dits.
		Schistes à Cardium palmatum.
		Calcaires de Trelon.
		Cuboides Beds.

The relation of this horizon for *Cardiola retrostriata* and its American horizon will be well seen in the following list of the most characteristic fossils of the formations lying in immediate juxtaposition to the "Schistes à Cardium palmatum." This is quoted from a section between Mariembourg and Frasnes, given by Gosselet. (*Loc. cit.*)

1. *Schistes de Famenne*:

Rhynchonella cuboides: Hamilton group.

R. pugnus: Chemung sandstones.

Spirigera concentrica: Hamilton group.

Spirifera disjuncta: Chemung sandstones.

S. euryglossa.

S. Murchisoniana.

Productus subaculeatus: Chemung sandstones.

³⁴Verstein. des Rhein. Schichten-Syst., Pl. XXVIII, Figs. 8, 9, 10.

³⁵Lethæa Palæozoica, Taf. XXXV, Fig. 16.

³⁶Beitr. zur Kenntn. d. Nordw. Harz, Taf. IV, Fig. 11.

³⁷*Loc. cit.*

³⁸Beitr. z. geol. Kennt. d. Nordw. Harz, Taf. IV, Fig. 11.

³⁹Annales d. Mines, Ser. 6, Tom. XII, p. 595, 1867.

2. *Schistes à Cardium palmatum*: (*Cardiola retrostriata*); *Naples shales*.
Goniatites retrorsus: *Naples shales*.
Rhynchonella bijugata.
3. *Schistes à nodules argilo-calcaires* (*Calcaires de Trelon*):
Rhynchonella cuboides: *Hamilton group*.
Atrypa reticularis: *Hamilton group*.
Rhynchonella bijugata.
Spirifera euryglossus.

The species of these higher Devonian beds have been subject to much greater recurrence in Europe than in America, as was early noticed by Bigsby.⁴⁰ *Rhynchonella cuboides* Sowerby, is fairly diagnostic of the lower Upper-Devonian and the American species after its type, *R. v-nus-tula* Hall, originally identified as *R. cuboides* by Conrad, which occurs only, as far as known, in the Tully limestone, at the base of the Genesee shales, is strong evidence of approximate parallelism of the Tully limestone and the European beds containing *R. cuboides*, viz., the Eifel cuboides kalk, the Aix-la-Chapelle cuboides schichten, the Iberger kalk of the Harz Mountains, etc.

Rhynchonella pugnus Sowerby, which ranges into lower horizons in Great Britain and Europe than America, is to be regarded as an Upper Devonian or Lower Carboniferous type, and in the section given it occurs in its normal position in association with *Spirifera disjuncta* Sowerby (*S. Verneuili*), a brachiopod distinctly upper Upper-Devonian in its type and in America exclusively so in its species, but which in Belgium, France, and the Rhineland ranges below its normal horizon into the cuboides beds. *Productus subaculeatus* Murchison is in Europe an Upper Devonian fossil, ranging occasionally into the Middle Devonian. In New York, Hall has identified it from the Corniferous limestone or Lower Devonian, but, according to Bigsby, de Verneuil has mentioned two species very similar to *P. subaculeatus*, collected by Lyell from Tioga. If by this Tioga County, New York, is meant, it would be within a district of Chemung outcrops. The "*Schistes à Cardium palmatum*" are described by Gosselet as black or violet-black, fissile shales, and are very like the bituminous beds of the Genesee and Naples shales.

Cardiola retrostriata is also quoted⁴¹ from the shales of Torbay, in Devonshire, with *Goniatites retrorsus*, *Bactrites Schlotheimii*, and *Pleurotomaria turbinea*, which Lee regards an Upper Devonian horizon. Leonhard⁴² has mentioned the species from Novaja Semlia. But the species is not confined to Upper Devonian horizons. Bigsby⁴³ quotes it from the Middle Devonian "*Calcaire de Givet*." Maurer⁴⁴ refers to this species a form from the *Wissenbach slates* of the Ruppbachthal, Lower Devonian. Von Seebach has mentioned it from the *Wissenbach* (*Goslar*)

⁴⁰ Quar. Jour. Geol. Soc., Vol. XIV, 1858.

⁴¹ Lee, Geol. Mag. new ser., Vol. IV, p. 100, 1877.

⁴² Ueb. paläoz. Gebilde im Nord-Deutchl. u. Belg., 1844, p. 139.

⁴³ Thesaurus Devonico-Carboniferus, p. 166.

⁴⁴ Neues Jahrbuch, 1876, p. 808.

shales of the Harz, that is, lower Upper Devonian. Barrois⁴⁵ has found Sandberger's var. *angulifera* in the "Schistes de Porsguen" of La Rade de Brest, which he refers to the Lower Devonian. It also occurs in the Bohemian Upper Silurian, *Étages E.* and *H.* In America its vertical range is much more limited. I have the species from the Hamilton shales of Hopewell, Ontario County, and a single specimen from the bituminous Marcellus shales, giving thus the species a range from the base of the Middle Devonian to the base of the Chemung group proper.

Genus *CARDIOLA*.

38. *Cardiola Doris*.

Cardiola Doris Hall, 1883, Pal. N. Y., Vol. V, Pt. I. Plates and Explanations, Pl. LXX, Figs. 10, 11.

A rather rare species, associated with *Lunulicardium ornatum* and *L. acutirostrum*. From Parrish Gully.

Genus *CARDIOMORPHA*.

39. *Cardiomorpha suborbicularis*.

Myalina suborbicularis Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 243.

Cardiomorpha suborbicularis Hall, 1877, Miller, Am. Pal. Foss., p. 186. 1883, Hall, Pal. N. Y., Vol. V, Pt. I. Plates and Explanations, Pl. LXIII, Figs. 9, 10. Not *C. suborbicularis* Sandberger.

This is a very abundant species in the lower shales, and very strongly suggests *Cardiola concentrica* v. Buch, of the lower Upper-Devonian of Westphalia and the Harz.

Genus *LUNULICARDIUM*.

40. *Lunulicardium ornatum*.

Lunulicardium ornatum Hall. *Pinnopsis ornata* Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 244.

Lunulicardium ornatum Hall, 1877, Miller, Am. Pal. Foss., p. 193. 1883, Hall, Pal. N. Y., Vol. V, Pt. I. Plates and Explanations, Pl. LXXI, Figs. 25-29.

A characteristic species, occurring first in the lowest green shales of the group at Cook's Point, on Canandaigua Lake, and in the beds immediately underlying the lower black band in Snyder's Gully, south from Woodville.

⁴⁵Annales de la Soc. Geol. du Nord., Tom. IV, p. 89, 1877.

41. *Lunulicardium acutirostrum*.

Pinnopsis acutirostra Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 244.

Lunulicardium acutirostrum Hall, 1877, Miller, Am. Pal. Fossils, p. 193.
1883, Hall, Pal. N. Y., Vol. V, Pt. I. Plates and Explanations, Pl. LXXI, Figs. 30-32.

Not uncommon in the soft shales of Parrish Gully, Briggs' Gully, and elsewhere.

42. *Lunulicardium fragile*.

Avicula fragilis Hall, 1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 222.

Aviculopecten fragilis Hall, 1877, Miller, Am. Pal. Fossils, p. 184.

Lunulicardium fragilis Hall, Am. Pal. Fossils, p. 193.

L. fragile Hall, 1883, Pal. N. Y., Vol. V, Pt. I. Plates and Explanations, Pl. LXXI, Figs. 1-14.

A characteristic and abundant fossil in the Genesee shales, losing its abundance with the close of the "transition shales," and to be found but sparingly in the Naples beds. My specimens are from Parrish Gully.

BRACHIOPODA.

Genus LINGULA.

43. *Lingula ligea*.

Lingula ligea Hall, 1860, Thirteenth Ann. Rep. N. Y. State Cab. Nat. Hist.
L. ligea var. Hall, 1867, Pal. N. Y., Vol. IV, Pl. II, Fig. 8, p. 8.

I have of this species but two individuals, one from the soft shales of Cashaqua Creek, Livingston County, and the other from the higher sandy shales at Naples. Mr. Hall's specimens are quoted from the arenaceous layers of the group.

44. *Lingula triquetra*, n. sp.

(Plate III, Fig. 11.)

Shell comparatively large, broadly spatulate, the sides sloping away very evenly from the apex at an angle of about 50 degrees, and rounding somewhat abruptly to the anterior margin, which is very transverse. In the ventral valve the apical angle is more acute than in the dorsal, projecting slightly over the dorsal apex; the width of the shell on the anterior margin nearly equal to three-fourths the length of dorsal valve. The surface is ornamented by concentric ridge-like lines of growth, which are not all of the same size. No evidence of radiating, decussating lines. Length of dorsal valve, 18^{mm}; greatest width, 13^{mm}; length of ventral valve, 19½^{mm}. This species resembles somewhat *L. lena* H.

and *L. palæformis* H. of the Hamilton shales, but differs from the former in being shorter, more transverse on the anterior margin, and with straighter sides, and from the latter in its relatively less width anteriorly, more abrupt anterior marginal angles, and the absence of radiating striæ.

BRYOZOA.

Genus AULOPORA.

45. *Aulopora annectens*, n. sp.

(Plate III, Fig. 15.)

A single specimen of this species attached to a valve of *Lunulicardium ornatum* has a creeping polyzoarium, polyp-cells scattered at nearly equal intervals along it. The sclerenchyma is flattened and the polyp-cells evenly sessile, opening directly from the base of the polyzoarium. Polyp-cells shallow, and with a number of deep striations on the inner surface, making pseudosepta. This is from the sandy layers in the lower beds of the group on Whale's Back, Canandaigua Lake.

CRINOIDEA.

Genus MELOCRINUS.

46. *Melocrinus Clarki*.

Melocrinus Clarki H. S. Williams, 1882, New Crinoids from Rocks of Chemung Period., Proc. Acad. Nat. Sci., Phila., p. 31.

This species has been found by Mr. Luther in the shales of Hatch Hill, Naples, occurring in the same manner as in the Genesee strata, a single thin layer, which is a mass of calices and columns. It is the only crinoid yet known from this group in Ontario County.

PLANTÆ.

Genus LEPIDODENDRON.

47. *Lepidodendron primævum*.

Lepidodendron primævum Rogers, 1858, Geol. Survey of Pennsylvania, Vol. II, Pt. II, p. 828.

Specimens referable to this species occur commonly in the upper bituminous layers in Naples and in the township of Sparta, Livingston County. Usually they are in a poorly preserved, decorticated "Knorria" condition. Outside of these bituminous strata the species is of rare occurrence. A specimen very remarkable for its size and beauty of preservation has been found by Mr. Luther in the upper sandy shales of the group at the

opening of Grimes's Gully, in Naples. This is a long trunk, measuring along the flattened edge 70^{mm} in width. When found only this transverse edge was exposed, and the trunk ran directly back into a thick bed of compact shales, so that it became necessary to remove several hundred cubic feet of this rock in order to expose it. Already a length of 225^{cm} has been worked out, the diameter of the flattened trunk constantly increasing the further the rock has been penetrated, and it measured 130^{mm} in section at the spot where it was necessary to break it off on account of the enormous mass of rock overlying. I trust that soon the remainder of this remarkable specimen may be uncovered, and believe that we may eventually find the root attached.

48. *Lepidodendron gaspianum*.

Lepidodendron gaspianum Dawson, 1860, Canadian Naturalist and Geologist, Vol. V.

Good specimens referable to this species are to be found in the higher sandy shales of the Tannery Gully, in Naples.

Genus CYCLOSTIGMA.

49. *Cyclostigma affine*.

Cyclostigma affine Dawson, 1881, Quar. Jour. Geol. Soc., Vol. XXXVII.

This species, which was founded on specimens taken from the horizon of the Naples shales in the adjoining county of Yates, I have found in the bituminous beds in Sparta. The specimens have been identified by Dr. Dawson as belonging to this species.

Genus FUCOIDES.

50. *Fucoides graphica*.

Fucoides graphica Vanuxem, 1842. Geol. N. Y., Survey Third Geol. Dist., p. 172.

This paradoxical fossil occurs very widely distributed throughout the flagstones of the group, always as long, low, oval elevations on the under surfaces of the slabs, a fact which proves that whatever the nature of the fossil may be it represents only the fillings of depressions on the originally muddy sea-bottom. These may have been formed by the wallowing of some animal, or by the decomposition of sea-weed over the bottom, but it is impossible yet to decide their true origin, as they have not been sufficiently investigated.

A number of other species have been described from the rocks of this age in New York State by Conrad, Hall, Dawson, and Williams, which I have not as yet been able to find in the district under consideration. Some of these cannot be identified on account of lack of completeness in the original definition of the species. This is especially true of the Pelecypoda, of which I have a large number of unidentified forms, any

description of which I feel obliged to defer, as Mr. Hall's study of these fossils is just issuing from the press, and probably any descriptions of mine would increase the unfortunate confusion which has hitherto existed in regard to the New York Devonian Pelecypoda.

The following species must be added to complete the list of the known fauna of these rocks:

Gomphoceras Ajax Hall.

1879, Pal. N. Y., Vol. V, Pt. II, p. 350, Pl. XCIV, Fig. 8.

This species was described from the shales of the Portage group, at Penn Yan, N. Y.

Orthoceras Thyestes Hall.

1879, Pal. N. Y., Vol. V, p. 306., Pl. LXXXVIII, Fig. 2.

An exceptionally large and robust species "from the soft shales of the Portage group, near Watkins," Yates County.

Orthoceras Atreus Hall.

1879, Pal. N. Y., Vol. V, p. 305, Pl. LXXXVIII, Fig. 1, and Pl. LXXXIX, Figs. 10, 11.

Another extremely robust species quoted from the "Calcareous layers of the Portage group, at Penn Yan," Yates County, and from near Portageville on the Genesee River.

Conularia congregata Hall.

1876, Illus. of Devonian Fossils, Pl. XXVIII, Fig. 1.

1879, Pal. N. Y., Vol. V, Pt. II, p. 214, Pl. XXXIV, Fig. 1; Pl. XXXIVa, Figs. 9, 10, 11.

This is cited "from the shales of the Portage group, near Ithaca, N. Y."

Avicula triradiata Conrad.

1842, Vanuxem, Geol. N. Y., Survey Third Geol. Dist.

Not mentioned by Hall in his final report on the Aviculidæ, 1884.

Lucina retusa Hall.

Nucula lineolata Hall.

Astarte subtextilis Hall.

1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 245.

These species, early described by Hall, do not appear in his recent monograph of the Devonian Pelecypoda.

Cardiomorpha undulata Hall.

1883, Pal. N. Y., Vol. V, Pt. I. Plates and Explanations, Pl. LXIII, Fig. 16.

Cardiomorpha textilis Hall.

1883, Pal. N. Y., Vol. V, Pt. I. Plates and Explanations Pl. LXIII, Figs. 11-15.

Præcardium vetustum Hall.

1883, Pal. N. Y., Vol. V, Pt. I. Plates and Explanations, Pl. LXX, Figs. 18-20.

I have not had opportunity of comparing these figures with my specimens.

***Orthis tenuistriata* Hall.**

1882, Geol. N. Y., Survey Fourth Geol. Dist., p. 246.

No mention has been made of this fossil in Hall's monograph of the New York Devonian Brachiopoda, and it is hardly to be regarded as a member of this fauna.

Spirifera lævis* Hall.**Delthyris lævis* Hall.**

1843, Geol. N. Y., Survey Fourth Geol. Dist., p. 245.

***Spirifera lævis* Hall.**

1867, Pal. N. Y., Vol. IV, Pl. XXXIX, p. 239.

This species, which is not uncommon in localities east of Ontario County, seems limited to those beds. I do not know of its occurrence west of Tompkins County.

Crania centralis* Hall.**1879, Pal. N. Y., Vol. V, Pt. II, Pl. LXXXVIII, Fig. 2, under explanation of the figure of *Orthoceras Thyestes*.Cyathocrinus ornatissimus* Hall.**

1-43, Geol. N. Y., Survey Fourth Geol. Dist., p. 247.

The individuals upon which this species was founded were taken from the Portage shales at Portland, on Lake Erie. I have no knowledge of its having been found in any other locality, and the species has never as yet been carefully diagnosed.

Poteriocrinus (Decadocrinus) Zethus* Williams.**Taxocrinus ithacensis* Williams.*****Taxocrinus curtus* Williams.**

1882, New Crinoids from the Chemung group of New York.

These three species, described by Dr. Williams, from the vicinity of Ithaca, I have not as yet found.

***Ormoxylon Brianum* Dawson.**

1871, Fossil Plants of Silur. and Dev. of Canada.

***Astropteris Novoboracensis* Dawson.**

1881, Quar. Jour. Geol. Soc., Vol. XXXVII, p. 299, Pl. XII, Figs. 1-9.

***Equisetides Wrightiana* * Dawson.**

1881, Quar. Jour. Geol. Soc., Vol. XXXVII, p. 301, Pl. XII, Fig. 10; Pl. XIII, Fig. 20.

The last two of these species were described from specimens found in the adjoining county of Yates.

* In the Geological Magazine for September, 1884, T. R. Jones and H. Woodward, regarding the original of this species as the abdominal segments of a Phyllopod crustacean, have thus described it, under the name *Echinocaris Wrightiana*. If this is correctly referred the original animal must have been of colossal dimensions.

THE PETROGRAPHIC AND PALEONTOLOGIC CHARACTERS OF THE PORTAGE BEDS.

TYPICAL EXPOSURES.

1. In the town of Naples, the Grimes and Tannery Gullies; on Hatch Hill; on the Garlinghouse road, and at Ingleside.
2. In the town of Italy, Yates County, the Clark Gully.
3. At Dansville, Livingston County.
4. On the Genesee River at Portageville.

From the highest horizon referred to the preceding group of shales, rise about 600 feet of heavy bedded gray and greenish sandstones, with some flagstones near their base, and occasional interlaminae of arenaceous shales. These were originally grouped with the Cashaqua and Gardeau divisions of Hall, as has already been noticed, under the name Portage group, and it may be that this was done more on negative than positive evidence, as these sandy layers are very barren of all organic remains. The paleontological connection between these Portage sandstones and the underlying Naples shales is very slight, and between the two must be drawn the line which separates the fauna of the Hamilton period from that of the Chemung. The original description of Hall characterized these sandstones by the abundance of the worm-borings *Scolithus (Fucoides) verticalis*, and these I have found to be quite abundant, especially at the top of the series and immediately underlying the beds bearing the important High Point Fauna presently to be noticed more at length. At Ingleside, in the township of Naples, I have found in these sandstones *Dictyophyton tuberosum* H., a fossil referred to the Hexactinellid sponges by Hall,⁴⁷ Whitfield,⁴⁸ Barrois,⁴⁹ and to the Algæ by Roemer;⁵⁰ also, *Ambocelia umbonata* Conrad; these about 500 feet below the summit of the group on High Point, 3 miles west of the village of Naples. *Dictyophyton tuberosum* I have also found within 300 feet of the upper limit mentioned. This fossil must be regarded as characteristic of the Chemung fauna, as it is not known to occur outside of Chemung horizons.

⁴⁷Thirty-fifth Ann. Rep. N. Y. State Mus. Nat. Hist., 1883.

⁴⁸Am. Jour. Sci., Vol. XXII, July and Aug., 1881.

⁴⁹"Dictyospongiae des Psammites du Condroz," Annales de l. Soc. Geol. du Nord, Tom. XI, 1883.

⁵⁰"Bemerk. neb. Hall's Gattung *Dictyophyton*." Sitzungsber. der schlesisch. Gesell. für vaterländ. Cultur, 1883.

Ambocælia umbonata is also a characteristic and abundant Chemung fossil, though it occurs as a member of the Hamilton fauna, 1,000 feet below. In the sandstones and flags of Grimes's Gully, in Naples, at a distance of about 600 feet below the High Point horizon, I have found the Chemung fossils *Leiorhynchus mesacostalis* H. and (?) *Discina leoni* H. Besides these, Mr. Luther has more lately detected *Ambocælia umbonata* Con., *Atrypa aspera* H., *Stenochisma eximium* H., and some unidentified species of *Productella*. Below this fossiliferous stratum and within 10 feet of it are beds containing the characteristic species of the Naples shales, viz., *Cardiola retrostriata*, *Goniatites complanatus*, *Colcolus aciculum*. Further than the six species mentioned, all of which are characteristic of the typical fauna of the Chemung, I know of no other fossils from these Portage sandstones, with the exception of the crustacean species described by myself, viz., *Spathiocaris Emersoni*, *Dipterocararis Procne*, *D. pennæ-Dædali*, from the beds in the town of Canadice, and *D. pes-cervæ* from Dansville, Livingston County. There are thus ten well-defined fossils (exclusive of *Fucoides graphica* and *Scolithus verticalis*) which constitute the known fauna of the Portage sandstones, two of which, namely *D. pennæ-Dædali* and *D. pes-cervæ* may be peculiar to it; seven belong to the Chemung fauna above, namely, *Dipterocararis Procne*, *Ambocælia umbonata*, *Atrypa aspera*, *Leiorhynchus mesacostalis*, *Stenochisma eximium*, (?) *Discina Leoni*, *Dictyophyton tuberosum*, and one comes over from the Naples fauna below, namely, *Spathiocaris Emersoni*.

The following table gives a list of all the fossils now known to occur in the Genesee and Naples beds in New York, and shows what portion of these faunas and floras have been derived from the rocks below of the Hamilton Period and what members pass upwards into the rocks of the Chemung Period. It therefore affords the evidence upon which the Naples shales and the Portage beds must be assigned to their appropriate horizons.

As a result of these investigations the fauna and flora of the old Cashaqua and Gardeau beds, i. e., the Naples shales, are increased by 32 species or 50 per cent. (for Ontario and adjoining counties, 66 per cent.), and of the Genesee shales the list is increased by 27 species or 48 per cent. of the known fossils of these rocks occurring in the State, and 60 per cent. of the known contents of the rocks in Ontario County and vicinity.

A list of the fossils occurring in the Genesee, Naples, and Portage beds of Ontario County, with the names of species heretofore identified from these horizons elsewhere in the State of New York, but not as yet known within this district.

Species.	Hamilton shales.	Genesee shales.	Naples shales.	Portage beds.	Chemung beds.
<i>Polygnathus dubius</i> Hinde	*	*	*		
<i>nasutus</i> Hinde		*			
<i>princeps</i> Hinde	*	*			
<i>palmatus</i> Hinde		*			
<i>punctatus</i> Hinde		*			
<i>Prioniodus erraticus</i> Hinde	*		*		
<i>spicatus</i> Hinde		*			
<i>angulatus</i> Hinde		*			
<i>armatus</i> Hinde		*			
<i>acicularis</i> Hinde		*			
<i>Dinictus Neuberryi</i> Clarke					
<i>Pristacanthus vetustus</i> Clarke			*		
<i>Palæoniscus devonicus</i> Clarke		*			
<i>Acanthodes pristis</i> Clarke			*		
<i>Necolitus verticalis</i> Hall			*		
<i>Ceratocaris longicauda</i> Hall		*		*	
<i>simplex</i> Clarke			*		
<i>Beecheri</i> Clarke			*		
<i>Echinocaris Whitfieldi</i> Clarke			*		
<i>Wrightiana</i> Dawson			*		
<i>Spathiocaris Emersoni</i> Clarke			*		
<i>Dipterocaris pennæ-Dædali</i> Clarke			*		
<i>pes-cervæ</i> Clarke			*	*	
<i>Proene</i> Clarke			*	*	
<i>Beyrichia Dagon</i> Clarke		*			*
<i>Goniolites complanatus</i> Hall	*		*		
<i>var. perlatus</i> Hall			*		
<i>discoideus</i> Hall	*	*	*		
<i>uniangularis</i> Hall		*	*		
<i>Patersoni</i> Hall		*	*		
<i>bicostatus</i> Hall		*	*		
<i>sinuosus</i> Hall		*	*		
<i>Lutheri</i> Clarke		*	*		
<i>nodifer</i> Clarke		*	*		
<i>peracutus</i> Hall		*	*		
<i>Chemungensis</i> Hall var		*	*		
<i>Astarte</i> Clarke		*	*		
<i>Orthoceras pacator</i> Hall		*	*		
<i>aciculoides</i> Clarke		*	*		
<i>Ontario</i> Clarke		*	*		
<i>Mosum</i> Clarke		*	*		
<i>Stegos</i> Clarke		*	*		
<i>Mephisto</i> Clarke		*	*		
<i>Asinodus</i> Clarke		*	*		
<i>Thyestes</i> Hall			*		
<i>Atrous</i> Hall			*		
<i>Gomphoceras Ajax</i> Hall		*	*		
<i>Manes</i> Hall		*	*		
<i>Conularia congregata</i> Hall			*		
<i>Hyolithes Neapolis</i> Clarke			*		
<i>Coleolus aciculum</i> Hall		*	*		
<i>Tentaculites gracilistriatus</i> Hall	*	*	*		
<i>Styliola fissusella</i> Hall	*	*	*		
<i>Bellerophon natator</i> Hall	*	*	*		
<i>incisus</i> Clarke		*	*		
<i>striatus</i> Fournasac and d'Orbigny		*	*		
<i>Euomphalus planodiscus</i> Hall		*	*		
<i>Loxonema</i> Noe Clarke		*	*		
<i>Palæotrochus præcursor</i> Clarke		*	*		
<i>Platyostoma minutissimum</i> Clarke		*	*		
<i>Belial</i> Clarke		*	*		
<i>Macrocheilus</i> (?) <i>Moloch</i> Clarke		*	*		
<i>Pleurotomaria capillaria</i> Conrad	*	*	*		
<i>rugulata</i> Hall	*	*	*		
<i>Itys</i> var. <i>tenutepira</i> Hall		*	*		
<i>Cardiola retrostriata</i> v. Buch		*	*		
<i>Doris</i> Hall		*	*		
<i>Cardiomorpha suborbicularis</i> Hall		*	*		
<i>undylata</i> Hall		*	*		
<i>textilis</i> Hall		*	*		
<i>Præcardium retustum</i> Hall		*	*		
<i>Lunulicardium fragile</i> Hall		*	*		
<i>acutirostrum</i> Hall		*	*		
<i>ornatum</i> Hall		*	*		
<i>Modiomorpha</i> (?) <i>Chemos</i> Clarke		*	*		

A list of the fossils occurring in the Genesee, Naples, and Portage Leds, etc.—Continued.

Species.	Hamilton shales.	Genesee shales.	Naples shales.	Portage beds.	Chemung beds.
<i>Spirifera levis</i> Hall			+		
<i>Belpheger</i> Clarke					•
<i>Pluto</i> Clarke		• •			
<i>Ambocoelia umbonata</i> Conrd.	•			• •	• •
<i>Atrypa aspera</i> Hall					
<i>Chonetes setigera</i> Hall	• •	• •			
<i>lepidia</i> Hall		• •			
<i>Leiorhynchus quadricostatus</i> Hall		• •			
<i>mesacostalis</i> Hall		•		•	•
(?) <i>Hecate</i> Clarke		•			
<i>Stenorhynchia eximium</i> Hall					
<i>Orania centralis</i> Hall		•	+		
<i>Discina truncata</i> Hall		•			
<i>Iodensis</i> Hall		•			
<i>Leoni</i> Hall (?)				•	
<i>Lingula tigea</i> Hall			•		
<i>spatulata</i> Hall		• •			
<i>concentrica</i> Vanuxem		• •			
<i>triquetra</i> Clarke			• •		
<i>Cyathocrinus ornaticornis</i> Hall		•	• •		
<i>Melocrinus Clarkei</i> Williams			• •		
<i>Poteroocrinus Zethus</i> Williams			• •		
<i>Tazocrinus Ithacensis</i> Williams			• •		
<i>curtus</i> Williams			• •		
<i>Aulopora annectens</i> Clarke		•			
<i>Cladochonus</i> sp.		•			
<i>Dictyophyton tuberosum</i> Hall				•	•
<i>Cyclostigma affine</i> Dawson		•			
<i>Asteropteria noveboracensis</i> Dawson			• •		
<i>Ormozylon Erianum</i> Dawson		• •			
<i>Dadozylon Clarkei</i> Dawson		• •			•
<i>Cladozylon mirabile</i> Dawson		• •			
<i>Lepidodendron princeum</i> Rogers		• •			
<i>Gaspianum</i> Dawson		• •			
<i>Calamites inornatus</i> Dawson		• •			
<i>Rachiopteris (Rhoda) pinnata</i> Dawson		• •			
<i>Fucoides graphica</i> Vanuxem			•	•	
<i>Sporangites Huronensis</i> Dawson		•			

Thus of 47 species occurring in the Naples shales of this district, 15 species or 34 per cent. occur also in the fauna of the Genesee; 1 species (3 including *Fucoides graphica* and *Scolithus verticalis*) or 2.1 per cent. in the fauna of the Portage; 9 species or 19 per cent. in the fauna of the Hamilton proper.

Of 32 species (not including 11 species belonging to the pyrite fauna) here noted as occurring in the Genesee shales of the district, 16 species or 50 per cent. occur also in the fauna of the Naples shales; 11 species or 34 per cent. in the fauna of the Hamilton proper.

Of 12 species which here occur in the Portage beds, 1 (3 ?) species or 8.5 per cent. is found also in the Naples shales; 7 species or 60 per cent. occur in the overlying Chemung beds.

There are two conclusions to be drawn from these tables, namely, (1) that the Naples shales have no such paleontological relation to the rocks of the Chemung Period as to justify the union of them with these rocks; (2) that their fauna and flora is more closely allied to those of the Hamilton shales, and that therefore these beds are to be regarded either as constituting the uppermost member of the Hamilton Period, or,

together with the Genesee shales, representing a distinct geological epoch.

From the facts (1) that only 10 of the 66 species which may be referred to the horizon of the Naples shales in New York, and 15 of the 56 species in the Genesee shales occur in the fauna of the Hamilton epoch, and (2) that as far as it is possible to trace a correspondence between these and transoceanic faunas they appear to belong to a lower Upper-Devonian horizon, and (3) that the transition from the Genesee to the Naples beds is so gradual petrographically and paleontologically that a very strong line of division between them is not possible, the more probable conclusion is that these two groups of strata represent the epoch of the lower Upper-Devonian in Western New York.

(105)

FAUNA OF CHEMUNG BEDS AT HIGH POINT.

Overlying the thick-bedded "sandstone with vertical fucoids," which was described by Mr. Hall as composing the terminal mass of the Portage sandstones, is a stratum 5 feet in thickness which contains a fauna of much interest. This was discovered in 1878 by Mr. D. D. Luther, on the summit of "High Point," a mountain standing 1,900 feet above the sea, and situated about 3 miles northwest of the village of Naples. The exposure of the stratum is quite limited, and, as it is *in situ* only on the sheer face of a high cliff, has been studied mostly from the fragments which have fallen into the talus below. I know as yet of no other outcrop of the stratum, although I have reason to believe that it will be found among the high hills lying to the south. The containing rock is a sandy limestone, or a sandstone, with a large intermixture of calcic carbonate brought in by the fossils it contains, and is in places largely composed of fragments of crinoid columns. It has afforded me the following fauna:

- Rhynchonella pugnus* Martin.
- Atrypa aspera* Hall.
- A. reticularis* Linnæus.
- A. hystrix* Hall.
- Streptorhynchus Chemungensis* Hall.
- Spirifera disjuncta* Sowerby.
- S. subattenuata* Hall.
- S. mesacostalis* Hall.
- S. bimesialis* Hall.
- Ambocoelia umbonata* Conrad.
- Strophodonta Cayuta* Hall.
- S. variabilis* Calvin.
- S. exilis* Calvin.
- Productella speciosa* Hall.
- Orthis infera* Calvin.
- Chonetes setigera* Hall.
- Crania* sp.
- Pterinea* sp.
- Polypora* sp.
- Fenestella* sp.
- Zaphrentis* sp.
- Receptaculites* sp.
- Dadoxylon Clarkei* Dawson.
- Rhynchodus* sp.
- Cladodus* sp., and other undetermined fish remains.

In the summer of 1882 I made Dr. H. S. Williams, of Ithaca, acquainted with the locality, and he has identified the following additional species:⁵¹

- Productella dissimilis* Hall.
- Orthis Iowensis* Hall.
- Strophodonta arcuata* Hall.
- S. (Strophonella) reversa* Hall.
- S. Canace* Hall and Whitfield.
- Spirifera Orestes* Hall and Whitfield.
- Stenochisma contractum* Hall.
- Fistulipora occidens* Hall and Whitfield.

Of this fauna only the following species had been previously recognized from the Chemung group of New York State:

- Atrypa aspera* Hall.
- A. reticularis* Linnæus.
- A. hystrix* Hall.
- Streptorhynchus Chemungensis* Hall.
- Strophodonta Cayuta* Hall.
- Spirifera mesacostalis* Hall.
- S. disjuncta* Sowerby.
- Productella speciosa* Hall.
- Chonetes setigera* Hall.
- Ambocalia umbonata* Conrad.
- Stenochisma contractum* Hall.

Rhynchonellæ very closely allied to *pugnus* Mart. have already been recognized in America by Meek⁵² in the subcarboniferous rocks of Rockford, Indiana, and Chouteau Springs, Missouri, in forms which are closely comparable to the English and Irish carboniferous forms. These have been referred to the species *R. Missouriensis* Shumard.⁵³ Marcou, in 1858, and McChesney, in 1860, described species of quite the same type as *R. pugnus*, the former under the name *R. Rockymontana*, the latter with the name *R. eatoniaeformis*, from the carboniferous of Utah and Illinois respectively. Although *R. pugnus* belongs to a carboniferous type, and occurs abundantly in the English and Irish carboniferous rocks, it is also in the same countries a member of the fauna of the Middle Devonian.⁵⁴ It is a well-known fossil in the Rhenish Devonian⁵⁵ throughout

⁵¹Am. Jour. Sci., Vol. XXV, Feb., 1883.

Dr. Williams has somewhat forestalled my work upon this fauna by the publication of this article upon A remarkable Fauna at the base of the Chemung Group in New York, but my observations here indorse and materially strengthen the *essential* views there set forth.

⁵²Geol. Survey of Illinois, 1866, Vol. II, p. 154.

⁵³Geol. of Missouri, 2d Ann. Rep. 1855, p. 204, and Meek, Geol. Survey of Illinois, Vol. II, p. 153.

⁵⁴Davidson, Mon. British Dev. Brach., p. 60.

⁵⁵Maurer, Neues Jahrbuch, 1875; Kayser, Zeitschr. d. d. Geol. Gesell., Band XXIII.

the Stringocephalen Kalk and the Upper Calceola Schichten, but here it is not to be regarded as a diagnostic fossil, inasmuch as its more usual occurrence is at a higher horizon. Kayser,⁵⁶ Roemer, and Schlönbach quote it from the vicinity of Eschweiler and Aachen, where it is associated with *Spirifera disjuncta* at a horizon which parallellizes with the Lower Chemung of America. In Belgium and the north of France it is quoted by Bureau⁵⁷ from the Cop Choux limestone, associated with *Rhynchonella cuboides*, and by Gosselet⁵⁸ from the "Schistes de Famenne," in association with *S. disjuncta* and *R. cuboides*, both of which horizons agree, as nearly as we can expect agreement in so widely separated formations, with the Chemung group of New York.

The forms of this species occurring in the Rhenish and Harz Devonian show a variation from the typical forms of *R. pugnus* figured by Davidson, and this author has referred the examples figured by the brothers Sandberger to *R. acuminata* Martin. Nowhere, to my knowledge, does this species in any one Devonian fauna present so considerable a variation as the specimens from High Point. Certain individuals with only a medium elevation of the mesial fold and with lateral plications acute at the margin, becoming obsolete over the visceral regions, represent the type of *R. pugnus*. Others, with extremely acute and elevated anterior margin and only traces of one or two lateral plications, represent the varieties of *R. acuminata*, *mesogonia*, or *plicata* Phil.⁵⁹ *R. pugnus* is one of several Devonian species of cosmopolitan range, and it has from the time of its first appearance in the Middle Devonian of Germany to its disappearance in the Lower Carboniferous, adapted itself to the change in the probable westward migration of the Devonian fauna of Europe, and has as a specific type outlived, without much variation, most of its earlier associates.

Dr. Williams has compared the fauna represented in the second of the lists given above with a peculiar and interesting fauna originally described by Hall⁶⁰ from Lime Creek, near Rockford, Iowa, and subsequently reviewed by Dr. C. A. White.⁶¹ By these two authors this fauna was regarded as belonging to the Hamilton group. Later Messrs. Hall and Whitfield⁶² published a study of the same fauna, describing some additional species, and referred it to the Chemung group, and more lately Mr. S. Calvin⁶³ has reviewed the fauna and given a complete list of its members as known to date. Calvin had also previously described⁶⁴

⁵⁶ Kayser, Zeitschr. d. d. Geol. Gesell., Band XXII, p. 841.

⁵⁷ Bull. Soc. Geol. de France, 2me ser., T. XVII.

⁵⁸ Bull. Soc. Geol. de France, 2me ser., T. XVIII, p. 18.

⁵⁹ Mon. British Dev. Brach., Pl. XIII.

⁶⁰ Geology of Iowa, Vol. I, Pt. II, 1858.

⁶¹ Geology of Iowa, Vol. I, p. 187, 1870.

⁶² Twenty-third Ann. Rep. N. Y. State Cab. Nat. Hist., 1873.

⁶³ Am. Jour. Sci., Vol. XXV, June, 1883.

⁶⁴ Bull. U. S. Geol. Survey, Vol. IV, No. 3, 1878.

an interesting fauna from a bed of black shales at Independence, Iowa, which *underlies* the main beds of the Devonian strata in that State, known as the Devonian limestones. The Rockford shales, containing the Lime Creek fauna, *overlie* these Devonian limestones, and several of the species occurring in the higher horizon are also found in these lower Independence shales. For the purpose of bringing out clearly the correspondence between the High Point fauna of Ontario County, and the fauna of the Lime Creek and Independence beds as given by Calvin, leaving aside the Cœlenterate fauna of the Lime Creek beds, the following table will suffice:

Species.	Independence shales.	Devonian limestones.	Lime Creek beds.	High Point beds.
<i>Naticopsis gigantea</i> H. and Whitfield			*	
<i>Paracyclas Sabini</i> White			*	
<i>Cryptonella Calvini</i> H. and Whitf			*	
<i>Terebratulina nancella</i> H.			*	
<i>Gypidula occidentalis</i> H.			*	
<i>Gyp. munda</i> Calvin	*			
<i>Leiorhynchus Iria</i> H.			*	
<i>Stenocoelasma contractum</i> , var. <i>saxatile</i> H.			*	*
<i>Rhynchonella ambigua</i> Calvin	*			
<i>R. pugnus</i> Martin	*			
<i>Atrypa reticularis</i> Linneus	*	*	*	*
<i>Atrypa hystrix</i> H.	*		*	*
<i>Atrypa aspera</i> H.				*
<i>Cyrtina Hamiltonia</i> , var. <i>recta</i>			*	
<i>Spirifer MacBridei</i> Calvin			*	
<i>S. fimbriata</i> Conrad			*	
<i>S. cyrtinaeformis</i> H. and Whitf.			*	
<i>S. Whitneyi</i> H.			*	
<i>S. subumbona</i> H.	*			
<i>S. Orestes</i> H. and Whitf.			*	*
<i>S. Hungerfordi</i> H.			*	*
<i>S. disjuncta</i> Sowerby			*	*
<i>S. mesacostalis</i> H.			*	*
<i>S. bimestialis</i> H.		*	*	*
<i>S. subbattenuata</i> H.		*	*	*
<i>Ambocoelia umbonata</i> Con.			*	*
<i>Productella truncata</i> H.			*	*
<i>P. dissimilis</i> H.	*		*	*
<i>P. speciosa</i> H.			*	*
<i>Chonetes setigera</i> H.			*	*
<i>Orthis impressa</i> , var. <i>lowensis</i> H.			*	*
<i>O. infera</i> Calvin	*		*	*
<i>Streptorhynchus Chemungensis</i> Con.			*	*
<i>Strophonella hybrida</i> H. and Whitf.			*	*
<i>S. reverei</i> H.	*		*	*
<i>Strophodonta exilis</i> Calvin	*		*	*
<i>S. variabilis</i> Calvin	*		*	*
<i>S. Canace</i> H. and Whitf.	*		*	*
<i>S. arcuata</i> H.	*		*	*
<i>S. Cayuta</i> H.			*	*
<i>Crania famelica</i> H. and Whitf.			*	*
<i>Pistulipora occidentis</i> H. and W.			*	*
<i>Dadozylon Clarkei</i> Dawson			*	*

This fauna in Ontario County consists of twenty-six described species, indisputably of the age of the Chemung Period, as it contains eleven species previously recognized from the Chemung group of New York, and lies 600 feet above the last stratum known to contain fossils of the Naples shales. But it embraces a large intermixture of species that are totally unlike those of the Chemung of New York, and which find their counterpart only at a distance of nearly 1,000 miles to the west. Fourteen species are common to the High Point strata and the Lime

Creek beds overlying the Devonian limestones. Of twelve species occurring in the Independence shales, which underlie these Devonian limestones, nine occur also on High Point. Two species of the intervening Devonian limestones, viz., *Spirifer bimesialis* H., and *S. subattenuata* H., occur likewise at High Point. With the occurrence of these Chemung fossils abundantly at the base at the top of the Devonian series in Iowa, it becomes difficult to assign any definite horizon to the members of that series which will give them a correspondence with series in New York. The character of the fauna of the Independence shales leads us to the belief that the first Devonian fauna to appear in Iowa included an important representation from the Chemung fauna of New York in its probable migration westward from New York, to be succeeded in the limestones and shales above by a mingling of the Middle and Lower Devonian faunas of the east, and again by a return of the Chemung fauna with a more perfect development at the time of the deposition of the Lime Creek beds. That is, in the matter of relative age, all of these Iowa Devonian beds must be later in time of deposition than the Devonian of New York lying below the horizon of the High Point strata, and the age which saw the deposition of the Chemung sediments in New York was probably well toward its close at the time of the inception of the conditions in Iowa necessary for the deposition of the Independence shales.

List of the new species described in this paper.

Species.	Genesee shales.	Naples shales.	Species.	Genesee shales.	Naples shales.
PISCES.			GASTEROPODA.		
1. <i>Diniethys Newberryi</i>	*		19. <i>Bellerophon inciens</i>		*
2. <i>Pristacanthus vetustus</i>		*	20. <i>Laxonema Noe</i>		*
3. <i>Palaeoniscus Devonicus</i>		*	21. <i>Platystoma minutissimum</i>		*
4. <i>Acanthodes pristia</i>		*	22. <i>Pl. Bellal</i>	*	
CRUSTACEA.			23. <i>Palaeotrochus praeursor</i>		*
5. <i>Ceratiocaris simplex</i>		*	24. <i>Macrochellus (?) Moloch</i>	*	
6. <i>C. Beecheri</i>		*	PELECYPODA.		
7. <i>Echinocaris Whitfieldi</i>		*	25. <i>Modiomorpha Chemos</i>	*	
8. <i>Beyrichia Dagon</i>	*		BRACHIOPODA.		
CEPHALOPODA.			26. <i>Spirifera Belphegor</i>	*	
9. <i>Goniatites Lutheri</i>		*	27. <i>Sp. Pluto</i>	*	
10. <i>G. Astarte</i>	*		28. <i>Leiorhynchus Hecate</i>	*	
11. <i>Goniatites nodifer</i>		*	29. <i>Lingula triquetra</i>		*
12. <i>Orthoceras aciculoides</i>		*	CELENTERATA.		
13. <i>O. Ontario</i>		*	30. <i>Anloporea annectens</i>		*
14. <i>O. flosum</i>		*			
15. <i>O. Stebos</i>	*				
16. <i>O. Mephisto</i>	*				
17. <i>O. Asmodeus</i>	*				
PTEROPODA.					
18. <i>Hyolithes Neapolis</i>		*			

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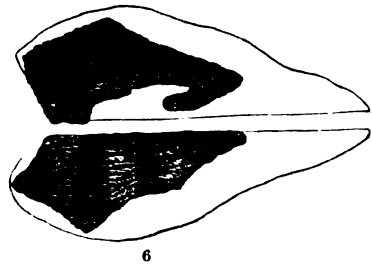
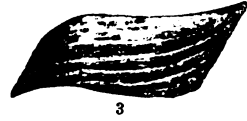
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○

(114)

EXPLANATION OF PLATE I.

- FIG. 1. *Diniotrys Newberryi* Clarke. Right lower mandible. $\times 4$.
FIGS. 2, 3. *Palæoniscus Devonius* Clarke. Scales. Fig. 2, $\times 2$; Fig. 3, $\times 10$.
FIGS. 4, 5, 6. The same. Cranial plates. $\times 2$.
FIG. 7. *Pristacanthus vetustus* Clarke. Spine. *Ad nat.*



DEVONIAN FOSSILS.

EXPLANATION OF PLATE II.

- FIG. 1. *Cerattochelis Boeckeri* Clarke. Showing three abdominal segments and the telson spines. *Ad nat.*
- FIG. 2. *Cerattochelis simplex* Clarke. Carapace. *Ad nat.*
- FIG. 3. *Echinocaris Whitfieldi* Clarke. Carapace. *Ad nat.*
- FIG. 4. The same. Caudal plate with two telson spines. *Ad nat.*
- FIG. 5. *Beyrichia Dagon* Clarke. Side view. $\times 20$.
- FIG. 6. The same. Dorsal view. $\times 20$.
- FIG. 7. The same. Ventral view. $\times 20$.
- FIG. 8. *Goniattites Lutheri* Clarke. *Ad nat.*
- FIG. 9. *Goniattites Astarte* Clarke. Side view. $\times 12$.
- FIG. 10. The same. Front view. $\times 12$.
- FIG. 11. *Orthoceras aciculoides* Clarke. $\times 2$.
- FIG. 12. *Orthoceras flosum* Clarke. *Ad nat.*
- FIG. 13. The same. Opposite side of the same individual.
- FIG. 14. The same. A younger example. *Ad nat.*
- FIG. 15. *Orthoceras Siebes* Clarke. $\times 12$.



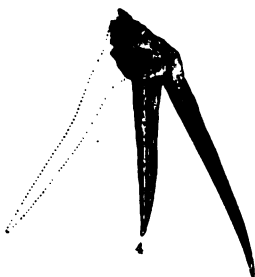
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8



14



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13



15

EXPLANATION OF PLATE III.

- FIG. 1. *Orthoceras Ontario* Clarke. *Ad nat.*
FIG. 2. *Orthoceras Mephisto* Clarke. $\times 12$.
FIG. 3. *Orthoceras Asmodeus* Clarke. $\times 30$.
FIG. 4. *Hyolithes Neapolis* Clarke. Dorsal surface. *Ad nat.*
FIG. 5. The same. Ventral surface. *Ad nat.*
FIG. 6. *Palaeotrochus praecursor* Clarke. *Ad nat.*
FIG. 7. The same. $\times 2$.
FIG. 8. The same. Showing the stoma. $\times 2$.
FIG. 9. The same. View from above. $\times 2$.
FIG. 10. *Loxonema Nos* Clarke. $\times 3$.
FIG. 11. *Lingula triquetra* Clarke. *Ad nat.*
FIG. 12. *Spirifera Pluto* Clarke. $\times 10$.
FIG. 13. *Spirifera Belphegor* Clarke. $\times 4$.
FIG. 14. *Leiorhynchus* (?) *Hecate* Clarke. $\times 10$.
FIG. 15. *Aulopora annectens* Clarke. *Ad nat.*



DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 17

ON THE DEVELOPMENT OF CRYSTALLIZATION IN THE IGNEOUS
ROCKS OF WASHOE NEVADA WITH NOTES ON
THE GEOLOGY OF THE DISTRICT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

ADVERTISEMENT.

[Bulletin No. 17.]

The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed in addition to the number in each case stated, the 'usual number' (1,000) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 2,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,000 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. 1v, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, and VIII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt., U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price \$10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price \$11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 8 pl. Price \$1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price \$1.35.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price \$1.05.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price \$1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price \$1.10.

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The following are in press, viz:

- IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. ix, 338 pp. 85 pl.
- X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 58 pl.
- XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. —, — pp. 46 pl.

The following are in preparation, viz:

- I. The Precious Metals, by Clarence King.
- Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.
- Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.
- Lake Bonneville, by G. K. Gilbert.
- Sauropoda, by Prof. O. C. Marsh.
- Stegosauria, by Prof. O. C. Marsh.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 17 are already published, viz:

- 1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.
- 2. Gold and Silver Conversion Tables, giving the coining value of Troy ounces of fine metal, etc., by Albert Williams, Jr. 1883. 8°. ii, 8 pp. Price 5 cents.
- 3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30', from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.
- 4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.
- 5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.
- 6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.
- 7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752-1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.
- 8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.
- 9. A Report of work done in the Washington Laboratory during the fiscal year 1883-'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.
- 10. On the Cambrian Fauna of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.
- 11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.
- 12. A Crystallographic Study of the Thimolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 8 pl. Price 5 cents.
- 13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 185 pp. Price 10 cents.
- 14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.
- 15. On the Mesozoic and Cenozoic Paleontology of California, by Dr. C. A. White. 1885. 8°. 33 pp. Price 5 cents.
- 16. On the higher Devonian Faunas of Ontario County, New York, by J. M. Clarke. 1885. 8°. 86 pp. 8 pl. Price 5 cents.
- 17. On the Development of Crystallization, etc., by Arnold Hague and J. P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

Numbers 1 to 6 of the Bulletins form Volume I, and numbers 7 to 14 Volume II. Volume III is not yet complete.

The following are in press, viz:

- 18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Dr. C. A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.
- 19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. — pp. Price — cents.
- 20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. — pp. 1 pl. Price — cents.
- 21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. — pp. 5 pl. Price — cents.

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STATISTICAL PAPERS.

A fourth series of publications having special reference to the mineral resources of the United States is contemplated.

Of that series the first has been published, viz:

Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

The second volume of this series, Mineral Resources 1883 and 1884, is in preparation and will soon be put to press.

Correspondence relating to the publications of the Survey, and all remittances, which must be by POSTAL NOTE or MONEY ORDER, should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C.

WASHINGTON, D. C., *May 20, 1885.*

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 17



WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

ON THE
DEVELOPMENT OF CRYSTALLIZATION

IN THE

IGNEOUS ROCKS OF WASHOE NEVADA

WITH

NOTES ON THE GEOLOGY OF THE DISTRICT

BY

ARNOLD HAGUE AND JOSEPH P. IDDINGS



WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., February 16, 1885.

SIR: I have the honor to present herewith a paper by Mr. Joseph P. Iddings and myself, on the development of crystallization in igneous rocks, the result of an investigation of the extensive and well-selected lithological material collected by Mr. George F. Becker during his examination of the Comstock lode.

Many field geologists have maintained that the acidic lavas and pumices occurring on or near the surface would be found changed to granite, if it were possible to trace them downward to great depth. This has been denied, especially of late years, by other equally eminent authorities, who have claimed that geological periods were characterized by crystalline rocks, differing in composition and structural features.

Although much has been written upon the relation between surface flows and deep-seated igneous rocks, the problems have never been solved. Indeed they could not be solved before the application of the searching methods of microscopical research now employed in the study of crystalline rocks. Few localities afford the necessary conditions, and none surpass the Washoe district in furnishing the requisites for a proper investigation of such questions.

So far as I know, the results of no similar investigation showing the gradual transition in crystallization under pressure in continuous rock-masses have ever been published.

As the results of the work lead us to definite conclusions upon some important questions and bear directly upon the geology of the Comstock lode, it seems desirable that they should be published by themselves in a special bulletin as early as possible.

Very respectfully, your obedient servant,

ARNOLD HAGUE,
Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey,
Washington, D. C.

ON THE DEVELOPMENT OF CRYSTALLIZATION IN THE IGNEOUS ROCKS OF WASHOE.

BY ARNOLD HAGUE AND JOSEPH P. IDDINGS.

INTRODUCTORY.

The Great Basin of Utah and Nevada, which has been the center of such widespread volcanic activity, presents the greatest possible variety of phenomena connected with the geology of igneous rocks. Within this well-defined area outbursts of lavas occur, forming high, rugged peaks, low, monotonous ridges interspersed with broad tables, extending for such long distances and covering such wide tracts of country as fairly to deserve the title of plateaus. Again, extravasated lavas may be seen as small isolated craters, as massive eruptions breaking out through lines of fissure and faults, and stretching out for miles along the base of the longitudinal ranges, or they may occur in small irregular hills, and occasionally in narrow dikes scattered over the country without any apparent law as to their distribution. Probably most geologists who have studied the region would agree that the country has nowhere been subjected to any extensive erosion since the outbursts of the greater part of these lavas. In consequence nearly all the later extrusions exhibit on the surface much the same features as they presented at the time they were forced upward through the underlying sedimentary strata or older crystalline rocks. While the region is one characterized by lavas of both acidic and basic types, presenting various glassy forms, there occur innumerable rocks showing every variety of microstructure, from nearly pure glass to others not only wholly crystalline but with a decided granitoid structure in the groundmass. The dikes which penetrate the older rocks are found in most cases to show a more crystalline structure than the massive eruptions or surface flows. This is especially the case with basic rocks; and although their connection with larger masses can seldom be traced, the conclusion seems inevitable that they must form portions of the same original magma, crystallized under different conditions. Although there has been collected throughout the area of the Great Basin a large amount of material which pointed in one direction and suggested a common origin and close geological connection between these extreme forms of rock

structure, the subject has not been before closely studied, and direct proof of such an identity has been wanting. This is in part owing to the fact that erosion has failed to cut deeply into any great flow showing variations of structure, and in part to the want of sufficient data and material from any one locality upon which a searching mineralogical and microscopical examination could be undertaken, which would afford the necessary proof to warrant the assertion that difference in structure was mainly the result of consolidation under varying degrees of heat and pressure, or an expression of the rate of cooling.

In studying the collections of lavas from the Pacific coast volcanoes¹ we were forcibly impressed with the insensible gradations in the micro-structure in the groundmass of rocks of the same mineral composition from a purely glassy form to one wholly crystalline, and corresponding exactly in structure to a fine-grained granite-porphyr. The chain of microscopical evidence seemed so complete that we were convinced that the glassy and crystalline rocks were simply the extreme forms of the same magma, and that a highly crystalline rock brought in for diabase from one of the ravines of Mount Rainier could be nothing less than a crystalline variety of the hypersthene-andesite, which, judging from the collections, makes up the greater part of the volcano.

In seeking a locality in the Great Basin which could afford the necessary conditions for carrying out such an investigation as we desired to make, showing the actual transition from the glassy to the granitic structure; it was readily seen that the Washoe district was the only place offering sufficient material for the work. Indeed, there are few localities in the world presenting conditions which would permit of such an inquiry, and so far as we know the investigation has nowhere been previously undertaken, at least upon material adequate for a satisfactory solution of the problem. For the means of making this investigation we are greatly indebted to Mr. George F. Becker, who placed at our disposal the large lithological collections which he and his assistants had gathered in the course of their field-work preparatory to his report on the geology of the district. Owing to the unprecedented activity in mining which has characterized the district during the twenty-five years of its existence, we are enabled to examine the interior of the mountain by actual sections in a way unsurpassed in any other place. In addition to the magnificent horizontal section, over 4 miles in length, shown by the Sutro tunnel, and numerous vertical sections cut by shafts from 2,000 to 3,000 feet in depth, it is estimated from the official maps and records of the mining surveyors that over 180 miles of galleries and other openings have been run, and although a large part of these galleries pass through quartz and ore-bearing material of the vein many miles of levels in exploring new ground penetrate in every direction the east and west country, laying bare the internal structure of the mountain.

¹ American Journal of Science, Vol. XXVI, September, 1883.

If the Virginia range were split asunder across the center of Mount Davidson it would not be possible to gain a more accurate knowledge of the region than is presented by this net-work of underground explorations. In the former case we should get a section of the mountain down to the level of the surrounding plain, but now we have, by means of the many deep shafts, a knowledge of the lower rocks many hundred feet below the level of the Carson Desert. And instead of a section cut on a vertical plane we have a mountain honeycombed in every direction by the untiring miner in search after bonanzas. Thus no natural section could surpass it for purposes of studying internal rock structure at great depths.

A mining region which has proved of such vast economic importance as the Comstock lode has necessarily excited intense geological interest, and owing to the great liberality of the National Government, scientific investigation of the district has gone on, with brief intervals of a few years, almost simultaneously with the exploitation of the precious metals. The amount of geological literature on the district which has been published is by no means inconsiderable, and a very large share of the space in the reports has been devoted to a consideration of the igneous rocks.

A brief summary of the results obtained by the more important investigators, including those of Baron von Richthofen,² Mr. Clarence King,³ Prof. Ferdinand Zirkel,⁴ and Dr. John A. Church,⁵ is given by Mr. Becker in his elaborate work on the Geology of the Comstock Lode, recently issued. Since the publication of von Richthofen's report, nearly twenty years ago, followed quickly by his monograph on The Natural System of Volcanic Rocks, the knowledge of crystalline rocks has advanced with rapid strides, and the science of microscopical petrography has been almost wholly developed. In this advancement the study of the Tertiary volcanic rocks of the Washoe district has played a conspicuous part. In selecting, then, this district for the special purpose of this work, we have been guided by the knowledge that the principal geological features of the region are within the reach of all students of petrography. The results of our investigation, undertaken merely as incidental to a study of the volcanic rocks of the Great Basin, have proved so much more satisfactory and convincing than we were at first led to hope that we have no hesitancy in publishing them at this time. Moreover, the geological conclusions reached from the study of the lithological material are in many ways so diametrically opposed to those of our predecessors that we offer no apology for adding another

²The Comstock Lode, etc. Ferdinand von Richthofen. San Francisco, 1868.

³United States Geological Exploration of the Fortieth Parallel; Vol. III. "Mining Industry." Clarence King. Washington, 1870.

⁴*Id.*, Vol. VI, "Microscopical Petrography." Ferdinand Zirkel. Washington, 1876.

⁵The Comstock Lode, etc. John A. Church. New York, 1879.

brief paper to the many already published on the geology of the Washoe district.

Mr. Becker, in agreement with his predecessors, divided the igneous rocks of Washoe into Tertiary and Pre-Tertiary species, differing with them widely, however, as to where the lines should be drawn, and adding one or two more varieties of Pre-Tertiary rocks to those already recognized. His work possesses the very great advantage over the labors of those who preceded him, in that not only the Sutro tunnel, but all the deeper shafts and galleries were accessible to him, a large amount of ground having been opened since the earlier geological investigations were made. This recent material is of great value. The rocks obtained from these lower workings, when subjected to microscopical examination, so closely resemble in structure the so-called Pre-Tertiary types, that Mr. Becker extended the domain of the "older" rocks over a considerable area at great depths below the surface. This same material from the deep-seated localities affords, it seems to us, abundant evidence that the so-called Pre-Tertiary and the Tertiary rocks pass by insensible gradations into one another, and that evidence of a difference in geological age is wholly wanting.

Mr. Becker classified the rocks under the following heads: Granular diorite, porphyritic diorite, micaceous diorite-porphry, quartz-porphry, earlier diabase, later diabase, earlier hornblende-andesite, augite-andesite, later hornblende-andesite, basalt.

Representing these rocks from all parts of the Washoe district, we have had placed at our disposal more than two thousand hand specimens, six hundred from the surface, and over fourteen hundred from underground. From this collection there are now more than five hundred thin sections, including a number recently prepared to fill up certain gaps in the chain of our argument. Of these specimens those from underground, with the exception of the Sutro tunnel rocks, were collected mainly within the immediate neighborhood of the Comstock lode, while the surface specimens are confined to an area about 5 by 7 miles in extent.

Let us begin our analytical work by submitting the rocks to a searching microscopical and macroscopical scrutiny, to show what points of agreement exist between the so-called Pre-Tertiary and Tertiary eruptions, comparing rocks of the same mineral composition with each other.

DIABASE AND AUGITE-ANDESITE.

In considering the relation between these closely related rocks we will first make a comparative study of the thin sections prepared from both series. In the collection there are about one hundred and forty thin sections determined as unquestionably diabase or augite-andesite,

and of these about twenty from each have undergone too much decomposition to allow of a satisfactory study of their feldspars, although they evidently agree in general characters with the fresher sections of the same class of rocks. Of the remaining one hundred thin sections forty were classed as diabase and sixty as augite-andesite.

Upon examining them somewhat hastily under the microscope two points are brought out in the most impressive manner. The first is the absolute identity in the nature and occurrence of the mineral constituents of the two rocks, and the impossibility of distinguishing many of those classed under one head from those classed under the other; the second is the gradual transition from a microlitic glassy groundmass to one holocrystalline, and from a microcrystalline groundmass of the minutest grain to one in which even the smallest grains are recognizable in thin section with the aid of an ordinary pocket lens. In studying them they may be arranged under eleven heads, according to the size and development of the grains of their groundmass, placing those with glass base at one end and those of the coarsest grain at the other. The different grades of crystallization may be stated approximately as follows:

1. *Groundmass* consisting of colorless glass, through which are scattered relatively few microlites of feldspar and pyroxene, and magnetite grains with contorted trichites. *Porphyritic crystals*, abundant plagioclase varying from 3^{mm} long to very small size, averaging 1 or 2^{mm} long; pyroxene crystals less numerous. Example, thin section 50.

2. *Groundmass* of colorless or light-brown glass crowded with microlites of feldspar and pyroxene, and magnetite grains, showing a typical "felt-like" structure. *Porphyritic crystals* the same as in grade 1. Examples, thin sections 239, 426.

3. *Groundmass*, holocrystalline, composed of feldspar microlites, and indistinct grains about .005^{mm} in diameter, with grains of pyroxene and magnetite. *Porphyritic crystals* as in grade 1. Example, thin section 422.

4. *Groundmass*, holocrystalline, composed of feldspar microlites and grains of pyroxene and magnetite, the cementing material being crystallized in irregular patches with uniform orientation for the space of about .03^{mm}. *Porphyritic crystals* as in grade 1. Examples, thin sections 121, 122.

5. *Groundmass*, holocrystalline, the same structure as in grade 4; but the indistinct patches about .05^{mm} in diameter, though not of uniform size throughout the thin section. The feldspar microlites measure about .02^{mm} long. It is sometimes composed of grains from .01 to .02^{mm} in length with feldspar microlites. *Porphyritic crystals* as in grade 1. Examples, thin sections 35, 420.

6. *Groundmass*, holocrystalline, the same structure as in grade 5; the patches averaging as high as .1^{mm}, full of feldspar grains .01^{mm} in diameter and feldspar microlites .05^{mm} long by .01^{mm} wide. *Porphyritic*

crystals, abundant plagioclase varying in different thin sections from an average of 1.5^{mm} to 2.5^{mm} ; pyroxene as in the preceding. Examples, thin sections 125, 389.

7. *Groundmass*, holocrystalline, composed of feldspar microlites about 0.1^{mm} long with granitoid grains of feldspar and quartz from $.01^{\text{mm}}$ to $.04^{\text{mm}}$ in size, together with grains of pyroxene and magnetite. *Porphyritic crystals*, plagioclase average about 2.5^{mm} , and begin to lose the sharpness of their outline. The same is true for the outline of the pyroxene sections. Examples, thin sections 169, 441.

8. *Groundmass*, holocrystalline, composed of granitoid grains of feldspar and quartz about $.06^{\text{mm}}$ in diameter, and lath-shaped plagioclase, in variable proportions, besides pyroxene and magnetite. *Porphyritic crystals*, plagioclase 2.5^{mm} and smaller; the outlines of some rather indistinct; pyroxene as in grade 7. Examples, thin sections 53, 173.

9. *Groundmass*, holocrystalline, granitoid grains of about 0.1^{mm} and ill-defined lath-shaped plagioclase. *Porphyritic crystals*, plagioclase of 3^{mm} and smaller, some with very irregular border; pyroxene as in grades 7 and 8. Example, thin section 215.

10. *Groundmass*, holocrystalline, granitoid grains, about 0.1^{mm} in size, with porphyritic crystals nearly equaling the groundmass in amount. *Porphyritic crystals*, plagioclase 3.5^{mm} and smaller; pyroxene showing little change. Example, thin section 55.

11. *Groundmass*, holocrystalline, composed of plagioclase feldspar of 1.5^{mm} and smaller, with fewer granitoid grains of about 0.1^{mm} . In places it shows fine pegmatoid structure, formed of quartz and plagioclase, surrounding plagioclase crystals. *Porphyritic crystals*, plagioclase 3^{mm} long; the sharply-defined zonal structure of the main mass of the crystal surrounded by a poorly-defined border of feldspar, which loses itself among the adjacent grains; pyroxene, sometimes in well-defined, frequently in irregular-formed, crystals. Example, thin section 213.⁶

⁶Agreeing with Professor Rosenbusch in general as to the origin of granular and porphyritic Structures in eruptive rocks; "Ueber das Wesen der körnigen und porphyrischen Structur bei Massengesteinen" in Neues Jahrbuch, 1882, II Band. We would briefly define the structural terms used throughout this paper as follows:

Granular.—The structure presented by an aggregation of grains of nearly the same size, or an aggregation in which there is a range in the size of grain, but with such a gradual transition that no particular individual stands out from the others in strong contrast.

Granitoid.—A structure in which the grains have an irregular form, produced by the mutual interference of adjacent crystals during their growth. The structure common to normal granites.

Porphyritic.—The structure which is produced when more or less well-defined crystals are imbedded in a groundmass, which is either glassy or holocrystalline, composed of crystals or grains of much smaller size than the imbedded crystals.

Pegmatoid.—The structure produced by the intergrowth of two or more minerals, usually quartz and feldspar, in such a manner that when seen in thin section they

In other words, we see that the porphyritic crystals show but slight modification in the different grades, the sharp outlines of the feldspars and pyroxenes being lost as the grains in the groundmass become larger, the nature of the inclusions in the feldspars also varying, as noticed further on. The essential variation takes place in the groundmass, which starting with a glass bearing few microlites, grows richer in them, then crowded until a very small amount of glass remains as a cementing base. This may be crystallized in microscopically cryptocrystalline particles, whose mineral composition is not determinable. As the size of the grain increases the cementing material assumes the appearance of uniformly oriented patches which, with increasing grain, are found to be in part quartz. In the higher grades the microlites have larger dimensions, and the cementing grains a granitoid form with or without pegmatoid structure.

In the highest grade (macroscopically a fine-grained porphyritic rock) it is difficult to draw any line between porphyritic crystals and groundmass, the more or less well-defined feldspars ranging from 3^{mm} in length to the size of the average granitoid grains of feldspar and quartz.

It is interesting to notice the appearance of a small amount of quartz as the last crystallizing mineral in the coarser-grained varieties of this pyroxene rock. It corresponds to the free silica, which remains after calculating the theoretical mineral composition from the chemical analyses of this rock, the excess being from 3 to 6 per cent.

Though the difference in the degree of crystallization between any two divisions of the scale is so slight, yet it represents more than actually exists, for the forms pass by imperceptible gradations into one another. If now the thin sections of both rocks are arranged according to this classification in columns as shown in Table I, we get at a glance some very striking results.

appear as groups of grains of more or less regular form, each group having one optical orientation throughout. It is similar to the structure in graphic granite.

Granophyre.—The variety of pegmatoid structure in which the intergrown minerals are arranged in radiating, plumose or feather-like forms.

Microcrystalline.—An aggregation of crystalline grains which can only be recognized as such by the aid of the microscope. This includes many rocks which would be macroscopically cryptocrystalline, aphanitic, or lithoidal.

Microcryptocrystalline.—An aggregate of crystalline particles so small that the highest magnifying power fails to resolve them into individual grains.

TABLE I.—*Grades of crystallization.*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Angite-andesite.....				499							
				877	465						
				822	447						
				818	440						
				243	828						
				187	821						
				186	815						
				184	286						
				147	180	378					
				140	178	181					
		428	453	122	177	175					
		426	422	74	143	125					
		239	816	62	44	124					
		45	138	39	42	69					
		48	187	83	80	38	158	173			
	50	87	41	32	35	81	441	72			
Diabase.....				115	308	16	15	1	14	55	27
				121	344	114	18	53	215		229
				338	346	341	54	349	348		
				374	365	357	77	433			
				410	405	389	169				
					420		312				
					276		336				
							339				
							340				
							350				
							386				

The numbers in this and the following tables refer to the thin sections in the Washoe collection.

It appears that the coarsest-grained rocks with a well-defined granular structure are found only in the so-called diabase, while the extreme forms of andesite, as seen in column 8, show a tendency to a development of the same structure. On the other hand, the glassy and cryptocrystalline varieties are confined exclusively to the andesites. Moreover, the rocks of medium grain include much the larger number of thin sections from both series, the greater part of the diabase showing a coarser structure than most of the andesites, with, however, only a difference of about .02mm in the size of grain. Now, each of the five grades (4 to 8 inclusive) for one rock has its exact counterpart in the other in size and shape of grain and structure of groundmass. On comparing the thin sections it becomes apparent that not only is the groundmass in each rock absolutely the same, but the porphyritic crystals are identical, giving the same results to every possible test that can be applied. They consist of the same species of triclinic feldspar, pyroxene, and occasional hornblende. The feldspars in rocks of corresponding grade present the same outlines, striations, similar extinction angles, zonal structure, and the same amount and character of inclusions. So much stress has been laid upon the nature of the inclusions in the feldspars⁷ that an exhaustive study was made of them, comparing thin sections from rocks of the same degree of crystallization without discovering any difference. In each thin section the individual feldspars exhibit great diversity in the nature and amount of their inclusions, some bearing scattered rectangular glass bodies, others abundant smaller ones

⁷ Geology of the Comstock Lode, page 50.

with rounded outlines, others being rich in grains of pyroxene and magnetite, others, again, combining all three, or, what is by no means uncommon, being nearly free from all inclusions. Fluid inclusions which might be considered primary are scarce in the medium-grained rocks, but were not found more abundantly in the "diabase" than in the andesite. As might be supposed, glass inclusions in the feldspars are more numerous in the glassy and fine-grained rocks, but upon careful search they may be observed in every thin section of the "diabase," from the finest to the coarsest. No line of demarcation can be drawn between these rocks based upon the glass-inclusions in their feldspars. In general, however, it may be said that the number of glass-inclusions decreases with increase in the degree of crystallization. In other words, they are a function of crystallization. This includes all thin sections given in the table, those in which the feldspars are clouded by decomposition being unfit for such a study. The fresh pyroxene consists of the same hypersthene and augite in both rocks, the hypersthene equaling or exceeding the augite in amount, and being the first to yield to decomposition.

Owing to the number of thin sections from these rocks and their various degrees of alteration, it is easy to trace the decomposition of hypersthene through all its stages, the augite in the same section remaining intact.⁸

This investigation leads then to the conclusion that in the thin sections of both rocks of the same degree of crystallization not only is the composition and structure of the groundmass identical, but that the relative abundance, size, and character of the porphyritic crystals scattered through this groundmass are the same.

Arranging now the hand specimens from which the thin sections were prepared in rows with the diabase and augite-andesite of the same degree of crystallization opposite each other, their macroscopic characters are seen to be identical. They agree in color, texture, fracture, and porphyritic crystals. Variations in one rock arising from stage of decomposition and amount and size of porphyritic secretions find their exact counterpart in the other. The conclusion then is inevitable that the greater part of the diabase is identical microscopically and macroscopically with the greater part of the augite-andesite and presents the transition between the glassy forms at one extreme and the coarsely crystalline forms at the other, and further, that the presence of a large percentage of hypersthene removes these rocks from the type of augite-andesite, properly so called, and places them under the head of pyroxene-andesite.

⁸ Notes on the Volcanic Rocks of the Great Basin, American Journal of Science, June, 1884.

SUTRO TUNNEL SECTION.

Having carefully examined all the specimens in the collection classed as diabase and augite-andesite, and shown that they belong to identical rock masses, let us now take up and study step by step the transition which occurs in a continuous rock mass along a definite line. For this work the Sutro tunnel, constructed for the purpose of draining the Comstock lode, furnishes an exceptionally fine geological section through 20,400 feet, or nearly 4 miles, of igneous rocks lying east of the vein. The tunnel enters near the lower foot-hills in Carson Valley, and runs a little north of west, approximately at right angles to the course of the vein and trend of the range, and directly toward Mount Davidson, the highest and largest mass of the mountain group. Probably few lines could have been selected more advantageously situated for exhibiting the structure of the region. A collection of two hundred and seventy specimens, carefully selected at intervals of 100 feet and less, together with their numerous thin sections studied in connection with the surface rocks immediately above ground, shows clearly the different kinds of rock which the tunnel penetrates and their variations in structure.

Referring to Sheet VI of the Atlas⁹ we observe that, starting from the mouth, the tunnel, according to Mr. Becker, passes through later hornblende-andesites with occasional masses of older augite-andesite, and at 10,000 feet enters the main body of the latter rock. Thin sections from about this point show it to be holocrystalline, of the grades 4, 5, and 6. The rocks for the next 2,000 feet are much decomposed, many of them full of pyrite. Between 11,400 and 11,700 feet occurs a dike of dense white rock, resembling a broad dike met with further in the tunnel. From 12,000 to 13,700 feet the andesites show more or less alteration, the porphyritic crystals being small, and the iron magnesia silicates indeterminable in the hand specimens. Of the five rocks in this part of the tunnel, of which we have thin sections, four carry hornblende associated with pyroxene, two showing a large amount of the former. At 13,700 feet a dike of quartz-bearing hornblende-pyroxene rock is met with possessing quite a different groundmass structure from that of the andesite through which it cuts. Between 13,800 and 13,900 feet another white dike occurs like that already mentioned, followed by a hornblende-pyroxene rock of coarse grain (grade 8). Here the tunnel cuts a dike 1,400 feet in width of a dense white rock carrying relatively few porphyritic crystals of feldspar and still less mica, but without hornblende or pyroxene, and having a groundmass-structure wholly unlike any found in the andesites. In the Sutro tunnel section this rock is indicated by lines of shading denoting solfataric action, but it is quite evident that it is younger than the andesite, as it is found penetrating it. The rock in every way corre-

⁹Geology of the Comstock Lode. Atlas, Sheet VI.

sponds in structure to the so-called felsitic quartz-porphyry from the surface near Roux's ranch and the Red Jacket mine.

Following this dike of white rock the next 1,000 feet of the tunnel cuts through augite-andesite, the nine thin sections of which range in grades of crystallization from four to seven, three showing hornblende. At 17,100 feet a characteristic rock is met, rich in fresh, brown hornblende, and having the same microstructure as the andesites previously observed (grade 7), yet so much less altered than the surrounding rocks on both sides that it seems evident that it occurs here as a dike. According to the published map section, however, there begins here a continuous body 1,500 feet in width of hornblende-andesite, but the hand specimens studied macroscopically show it to correspond in every particular to the augite-andesite; and of the eleven thin sections from this body, with the exception of the fresh rock above noticed, only two show small amounts of hornblende, the remaining eight not carrying any that could be definitely determined. They range in crystallization from grades 5 to 8 eight, and have the same microscopical character as the augite-andesite to the east. It appears to be cut in three places by mica-hornblende rocks differing essentially from the surrounding andesite, and corresponding in microstructure and mineral composition to the so-called mica-diorite from the head of Ophir Ravine (thin section 459). Referring again to Sheet VI, it will be seen that the tunnel after passing through the body represented as hornblende-andesite enters the diabase. Again, hand specimens from several hundred feet upon each side of the supposed line of contact are indistinguishable from one another, and the thin sections show identical structure and the same degree of crystallization.

Examining now the twenty-seven thin sections from the diabase cut by the main tunnel and the north and south branches,¹⁰ the first of which is 4,400 feet, and the second 4,000 feet in length, they are seen to vary in degree of crystallization (with one marked exception) from grades 5 to 10, averaging 8, or two grades higher than the average of augite-andesite. In the hanging wall west of the Savage mine connection the tunnel goes through diabase, and again also west of the vein, then passing through diorite it again cuts diabase 180 feet west of the Savage connection, and at the end encounters a mica-diorite like that observed further to the east. An examination of the thin sections recently made from the diorite showed in one case that the iron magnesia silicates, now completely altered to chlorite, were pyroxene and not hornblende, and in the other two cases, while their original nature is not determinable, the microstructure of the rocks is the same as that of the most crystalline diabase.

Let us reject for the present the thin sections which represent the dikes or later intrusions cutting through the main rock mass, and place

¹⁰Geology of the Comstock Lode. Atlas, Sheets VIII and IX.

the others in columns (Table II) according to the scale of crystallization, already adopted, arranging them in the order in which they occur in proceeding from the mouth to the head of the tunnel.

TABLE II.—Grades of crystallization.

	Distance from mouth of tunnel.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Angite-andesite	41			138								
	49				140							
	54					141						
	403					144						
	1,400					315						
	2,500			316								
	5,234				318							
	9,761				32							
	9,800					321						
	9,971				33							
	10,000				147							
	10,055						31					
	12,000						149					
	12,300			151								
	12,500				153							
	12,600				154							
	13,700						95					
	14,080								72			
	15,680						69					
	16,066					71						
	16,384				74							
	16,700				323							
	16,758					84						
	16,800					323						
	(†) 16,884							158				
	16,921					324						
	16,921					63						
	17,000					325						
Hornblende-andesite.....	17,100							326				
	17,300								327			
	17,500					328						
	17,600						290					
	17,700					329						
	18,100					330						
	18,300					331						
	18,500								332			
	18,600							333				
	18,700								334			
	19,000						335					
Diabase	19,155								22			
	19,200								58			
	19,454							77				
	19,540							79				
	19,700							80				
	19,805							15				
	19,910							18				
	* 19,910									14		
	19,971							100				
	20,100							336				
Diorite	(†)									506		
	20,120								506			
	20,160									507		
Diabase	South branch.			338				337				
								339				
								54				
								340				
	North branch.											
							341					
							342					
							343					
Diabase	South branch.					344						
						346						
Diabase	North branch.						16					
								350				
									17		348	
							347					35

* Hanging wall of Savage.

† Lode limit Savage.

The important points clearly brought out by the table are, first, that there is in general a gradual increase in the degree of crystallization of the rock from the outer foot-hills as the tunnel approaches the central core of Mount Davidson; second, that while the rocks classed as augite-andesite occur more at the lower end of the scale, and the diabase at the other, by far the greater part of both rocks overlap each other in the intermediate columns, and are indistinguishable from one another. The glassy forms of pyroxene-andesite, abundant enough on the surface, are unknown in the tunnel. It is worthy of note that as the north branch approaches Mount Davidson there is exhibited a tendency toward a coarser crystallization, while on the other hand the south branch, as it turns away from the central mass, indicates an equally strong tendency to a finer-grained structure.

GRANULAR DIORITE.

Reference has been made in the text and in Table II to the diorite at the head of the Sutro tunnel upon the west side of the Comstock lode, which we have placed with the pyroxene rocks. This rock, classed by Mr. Becker as granular diorite, forms the east front of Mount Davidson and presents the most conspicuous topographical feature in the district. Of the three specimens of granular diorite from Mount Davidson having thin sections only one (213) was originally determined as unquestionably diorite, the others being left doubtful. Thin sections recently prepared from three typical localities, namely, the summit of Mount Davidson (488), Ophir Ravine (489), and the Sutro tunnel (507 and 508), show that they are identical with those previously examined. Moreover, they agree in every particular of microstructure and mineral character with the coarsest-grained pyroxene rock found to the east of the vein from the north branch of the Sutro tunnel (55) and the C. and C. shaft (27).

The light-green, fibrous hornblende shows its uralitic nature by having the characteristic eight-sided outline of pyroxene in cross-section. Both the diabase from Ophir Ravine (216) and the diorite from the Savage mine (463) show the transition of the pyroxene into fibrous hornblende. While both rocks are at present hornblendic, it is evident that their hornblende is for the most part secondary, and that they are coarsely crystalline pyroxene rocks with the hypersthene and augite altered to uralite.¹¹

The identity of the granular diorite with the coarse-grained diabase

¹¹ The diorite from Ophir Ravine (40th Parallel Collection, No. 22620, thin section 157) shows both uralitic hornblende and fibrous hornblende, which appears to have resulted from primary hornblende. Some of the pargasite bears minute glass inclusions; the groundmass shows fine pegmatoid structure.

is well brought out on comparing thin sections 507, 508, 488, 489, 213, 214, 360, and 463 of the former with 14, 280, 215, 216, 27, and 55 of the latter; also on comparing hand specimens 109, 215, 303, 567, 568, and 1125 with 307, 264, and 364.

The difficulty of distinguishing between these rocks seems to have been realized by Mr. Becker, for he admits that the gray granular diorite may be mistaken for granular diabase;¹² and again, in speaking of the locality in Ophir Ravine,¹³ says: "This bears a very strong outward resemblance to a granular diorite, and it seems impossible to make out a sharp contact between the two rocks. I am by no means sure that it should not be regarded as a local modification of diorite rather than an independent eruption."

PORPHYRITIC DIORITE AND EARLIER HORNBLENDE-ANDESITE.

If we arrange the surface specimens on a table as nearly as possible in accordance with their relative positions on the map, we are at once impressed with the similarity between those labeled diorite and many classed as andesites and with the difficulty of establishing any line of demarcation between the two rocks. Another remarkable fact is the gradual transition from the most crystalline forms of which Mount Davidson is chiefly made up, outward as from a center to less crystalline and glassy varieties.

It soon becomes evident, upon a cursory examination carried on in the same manner as in the study of the proxene rocks that the different varieties of porphyritic diorites have as to macroscopical habitus their exact counterparts among the earlier hornblende-andesites. The following surface specimens may be cited for the purpose of comparison:

<i>Diorite.</i>	<i>Hornblende-andesite.</i>
481	like 157.
478, 474	" 493.
125	" 439.
483	" 211, 78, 528, 531.
482	" 213.
306	" 116.
449, 312	" 486, 487.
185, 477, 41	" 225, 184, 158.
59, 479, 42, 40	" 217.
558	" 494, 532, 536.

Every variety is here represented; there may be found those with large porphyritic crystals, and those with very small ones, ranging from much decomposed to quite fresh forms. They agree in texture and color of groundmass, in character of fracture and mode of weathering,

¹² *Loc. cit.*, p. 39.

¹³ *Loc. cit.*, p. 197.

and in size and relative abundance of porphyritic crystals. In a word, by every macroscopical test that can be applied they are indistinguishable in the hand-specimens. Taking up now the sixty thin sections representing the surface collection of both these rocks and subjecting them to the same comparative microscopical scrutiny applied to the pyroxene rocks, they still fail to present any distinguishing features. The groundmass of the porphyritic diorites varies from cryptocrystalline to microcrystalline, formed sometimes wholly of lath-shaped microlites, others having a granular structure with microscopic feldspars scattered through it. Now, for every variety of groundmass among the porphyritic diorites from the surface there can be found among the andesites identical rocks of the same degree of crystallization, corresponding in structure, size of grain, and mineral composition. The same identity holds good for the porphyritic crystals; the feldspars show the same inclusions, and the hornblendes and pyroxenes present precisely similar characters in both rocks. Quite in accordance with the observations upon the pyroxene-andesites there are a few hornblende-andesite sections which show glass in the groundmass, and at the same time a corresponding increase in the amount of glass-inclusions in the feldspars, but by far the greater number of rocks represented are holocrystalline.

MICA-DIORITE AND LATER HORNBLLENDE-ANDESITE.

The rocks classed by Mr. Becker as later hornblende-andesite¹⁴ we prefer to call hornblende-mica-andesite, for the reasons that they are characterized in distinction from the earlier hornblende-andesite by an abundance of mica as an essential ingredient, and are at the same time more acidic in composition; and while the name later hornblende-andesite answers well enough for the Washoe district, it is hardly applicable in other regions of the Great Basin where these rocks frequently occur, forming large extrusions without any association on the surface with earlier hornblende-andesite. The specimens in the collection vary greatly in the abundance and size of porphyritic crystals, in texture and color of groundmass, as well as in the relative proportions borne by the constituent minerals to one another. This variation in habitus is greater than in either hornblende or pyroxene andesite. The mineralogical features and diversity of habitus have been well described by Mr. Becker in his monograph.

The mica diorites are few in number and represent comparatively small masses scattered over the surface or exposed by the underground workings of the mines. Nevertheless when considered in connection

¹⁴ These rocks are the "trachytes" of Baron von Richthofen, Mr. Clarence King, and Prof. Zirkel. Mr. Becker has shown that according to the modern classification now generally adopted by lithologists they belong to the andesite group.

with the other mica bearing diorites in the collection they form a much larger class, presenting an equally varied structure and composition, and for each variation, with the exception of the more crystalline forms, the exact counterpart may be found among the later hornblende-andesites. By placing the corresponding forms in parallel rows, as in the case of the diorites and earlier hornblende-andesites, it is found quite impossible to distinguish them, the great variation in macroscopical appearance bringing out all the more forcibly the absolute identity of the two rocks.¹⁵

The thin sections clearly show the same correspondence in minute structure, although a thorough comparative study is not always possible, as the sections from the mica-bearing diorites are mainly from underground specimens exhibiting more or less decomposition, while those from the later hornblende-andesites are for the most part fresh. The only thin section (No. 101, 1,000 feet from the Silver Hill mine) of the fine grained mica-diorites in which the feldspars still remain unattacked exhibits glass inclusions in the fresh feldspars, and in the relatively coarse-grained varieties (grades 8, 9, 10) they may be seen in profusion, while they are almost wholly wanting in those of the coarsest grain (grades 12, 13, 14) which abound in liquid inclusions, as might be sup-

¹⁵ The following table represents the numbers of the hand specimens of the two rocks which correspond each to each:

Later hornblende-andesite.	Mica-bearing diorite.	
<i>From Sutro tunnel collection.</i>	<i>From surface collection.</i>	<i>From mining collection.</i>
7	505	
10, 11, 12	561	
29, 30		548, 821, 827, 755
31		827, 1459
32		804
33		764
34	563	
36	156	
43	556	
45, 112	554, 555	
75	557	
79	553	
84		578
90, 91		456
100		455
103	560	
105		802, 808 (b)
114		803, 1407
117		806, 807
118		458
<i>From surface collection.</i>		
26	11	
79		809 (b) 810 (b)
92	448, 475	888, 850, 1331
97		462
101	564	
103	159	
291	107, 550	1417, 1420
292	552	
293		805
302	562	405, 1247, 1271

posed. In this series of rocks also we see that the range from glass to liquid inclusions varies with the degree of crystallization, as already shown.

These last three grades of crystallization have the following characteristics, it being borne in mind that the iron magnesia silicates in the series in question differ from those of the series described on pages 13 and 14.

Grade 12.—More or less well-defined crystals of plagioclase, 3.5^{mm} and smaller, with very irregular patches of mica and hornblende, in a groundmass of most irregularly shaped, interlocking grains of feldspar and quartz, which range from 1.8^{mm} to 0.6^{mm} in diameter. Example, thin section 291.

Grade 13.—The average size of the granitoid grains somewhat larger than in grade 12, and exceeding in many cases the size of the better outlined crystals. Example, thin section 460.

Grade 14.—A thoroughly granitoid structure to all the mineral constituents, which range in size from 3.5^{mm} to others quite small, the greater part of them averaging as high as 1.5^{mm}. Example, thin section 268.

Arranging the thin sections according to their degree of crystallization (Table III), the scale adopted being approximately the same as that given in the table for the pyroxene rocks, the relation of the later hornblende-andesites to the mica-bearing diorites will be seen at a glance:

TABLE III.—*Grades of crystallization.*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Later hornblende-andesite.	483	478	475	471	467	462	457	452	447	442	437	432	427	422
	476	470	467	462	457	452	447	442	437	432	427	422	417	412
	474	320	390	385	380	375	370	365	360	355	350	345	340	335
	472	319	75	375	397	402	407	412	417	422	427	432	437	442
	48	317	66	375	397	402	407	412	417	422	427	432	437	442
	47	59	65	230	70	67	62	57	52	47	42	37	32	27
	46	51	64	49	67	62	57	52	47	42	37	32	27	22
	9	86	101	252	265	247	300	429	291	460	85	96	268	
		91	119	398	402	411	412	417	422	427	432	437	442	
		446	194	185	197	200	203	205	209	213	217	221	225	
Mica-bearing diorite.				172	185	197	200	203	205	209	213	217	221	
				172	185	197	200	203	205	209	213	217	221	
				172	185	197	200	203	205	209	213	217	221	
				172	185	197	200	203	205	209	213	217	221	
				172	185	197	200	203	205	209	213	217	221	
				172	185	197	200	203	205	209	213	217	221	
				172	185	197	200	203	205	209	213	217	221	

The extreme glassy form represented in the table of pyroxene rocks does not happen to occur among the thin sections of later hornblende-andesite, but a large proportion of them represent a glassy groundmass crowded with microlites, while all of them belong at one end of the

series. On the other hand all of the so-called mica-diorites possess a holocrystalline groundmass, range from finely microcrystalline to a macrogranular or granitoid structure, in which the smallest grains are visible to the naked eye. They reach a somewhat coarser grain than was recognized among the pyroxene rocks, the scale being extended from eleven, in Table I, to fourteen grades. As indicated in the table, the three highest grades of the andesite correspond to the three lowest of the diorite and are identical with them in microscopical detail. Moreover more than one-half the thin sections examined fall within these three grades. A separation of the two rocks from a petrographic standpoint seems to us quite impossible.¹⁶

QUARTZ-PORPHYRY, DACITE AND RHYOLITE.

Baron von Richthofen, in his study of the Washoe district, evidently paid but little attention to these rocks and dismissed them with brief mention, regarding them as of slight importance in questions bearing upon the geology of the vein. He considered them, however, as earlier than the Tertiary volcanic lavas. Mr. Clarence King, after careful examination of the field, referred them upon geological evidence to the Tertiary series, and Professor Zirkel, after a microscopical examination of the thin sections, determined them as belonging to both dacite and rhyolite. The results of Mr. Becker's investigation led him to the conclusion that the absolute uniformity of the rock masses precluded their separation into Tertiary and Pre-Tertiary eruptions, while geological observation and an examination under the microscope of certain specimens, following the same methods of reasoning as adopted for other rocks, induced him to agree with von Richthofen as to their age. From our own knowledge of the district¹⁷ and close study of the specimens and thin sections we have arrived at the conclusion reached by Mr. King as to the age of this series of rocks, and agree with Professor Zirkel as to their specific determinations.

Omitting for the present the geological evidences bearing upon the age of the rocks plotted on the Washoe map as quartz-porphyry, let us first consider their microscopical and macroscopical habitus. They are for the most part rich in porphyritic crystals of quartz, feldspar, and mica, with some hornblende, but vary greatly in the relative proportions

¹⁶ Similar petrographic relations apparently exist among the rocks of the Banat described by J. Niedzwiedzki in an article entitled "Zur Kenntniss der Banater Eruptivgesteine." *Tschermak's Mineralogische Mittheilungen*. 1873. iv, 255-261.

¹⁷ One of the writers of the present article was geological assistant to Mr. Clarence King when he made his study of the Comstock mines in the winter of 1867-'68 and is quite familiar with the occurrence of the igneous rocks of the Washoe district.

of these minerals. Those with few quartzes, but rich in feldspar, plagioclase being in excess of orthoclase, accompanied by much mica and less hornblende, correspond to dacite in mineral composition, and resemble the dacites from Mount Prometheus in the Toyabe Range. In others, characterized by abundant quartzes, plagioclase seems occasionally to predominate over orthoclase; but in most of them the latter feldspar is in excess, particularly in those poor in mica and hornblende. The region is one where not only both dacite and rhyolite occur, but one where the transition members are well represented.

In macroscopical habitus they exhibit great variations, arising from the abundance or scarcity and size of the porphyritic crystals, and from the color and density of the groundmass. Many hand specimens are perfectly fresh and show the brilliant sanidins so characteristic of the dacites and rhyolites of the Great Basin, and a microscopical examination proves conclusively their identity. The groundmass of many of them often shows within the small area of a square millimeter the greatest diversity of structure, being partly spherulitic, axioltic, and microcrystalline, with glass either clear or clouded (microfelsitic), presenting elongated, curved patches and streaks, a structure described in great detail by Professor Zirkel in his monograph on microscopical petrography already mentioned. The porphyritic quartz contains in most cases only glass, less frequently liquid inclusions, the latter, however, occurring in greater numbers than is usually met with throughout the Great Basin. As these rocks are somewhat removed from the center of mining activity, there are no good underground exposures, and in the few places where they have happened to be cut in exploration they show so much decomposition or occur so fine-grained as to offer very little variation in degree of crystallization. It may be said, however, that there exist no petrographic distinctions between these rocks and many of those found in the ranges to the eastward. We consider them as partly dacite and partly rhyolite, and, judging from the specimens in the collection, without any sharp line of demarcation between them.

YOUNGER DIABASE, BLACK DIKE, AND BASALT.

The rock considered by Mr. Becker as younger diabase and of Pre-Tertiary age is nowhere recognized on the surface. It only occurs as a narrow dike in the immediate neighborhood of the Comstock lode, where it has been followed for more than a mile along the lower levels of the mines. In the upper levels it has undergone so much decomposition that little could be made out of it by the earlier investigators, and for years mining engineers have designated it simply as the "black dike."

According to Mr. Becker, who has given careful attention to the occurrence of this rock, it has not been traced north of the Savage mine, but thence south to the Overman, "it generally marks the contact between the older diabase and the west wall with precision."¹⁸ It extends as far south as the Caledonia, presenting everywhere great uniformity, and never measuring more than 6 feet in width. The rock was represented by only three thin sections, showing but slight variations in structure, and composed of triclinic feldspar, augite, magnetite, and what Mr. Becker described as "clouds of a smoky brownish substance" which he did not determine. Now it is quite evident that much of this substance occupies spaces with the six-sided and lozenge-shaped outlines characteristic of olivine; this is well shown in thin section 274. Two new sections from the Yellow Jacket (1278) and the Belcher mines (1322) show in the former a coarser grain and in the latter a much finer grain, having a large amount of fine-grained groundmass with small porphyritic feldspars, augites, and decomposed olivines, the typical structure of many Nevada basalts.

The five thin sections, arranged in the following order, 509, 466, 289, 274, 511, present a gradual transition from coarser to finer grain, the porphyritic crystals diminishing in size and number as the rock becomes more and more porphyritic and carries more groundmass. The augites and feldspars are fresh, while the olivines are wholly decomposed to a greenish-brown fibrous substance, which is also disseminated through the groundmass. It is to be noted that the augite in this rock is quite fresh, while in many of the andesites it exhibits much alteration.

Turning now to the surface rock which has been regarded by every field observer as basalt, we find that it occupies very limited areas, only occurring in a few isolated patches, closely associated with the dacite and rhyolite in the neighborhood of American Flat. Thin sections from these surface rocks show a ground mass without the chlorite, similar to that in the underground rock (thin section 511), but with fewer and smaller porphyritic feldspars. The augite is of the same character, and the fresh olivine presents the same form and size as the spaces occupied by the "smoky brownish substance" in the black dike. Comparing hand specimens of the two rocks, those from the black dike are seen, as might be expected, to be slightly denser than the surface basalt. In specimen 1202 from the dike the decomposed olivines are especially prominent, and give the rock exactly the same habit as the basalt specimen 398, from southwest of Roux's ranch, the latter differing from it only in being somewhat porous, of a steel-gray color instead of greenish-black, and in having fresh, glassy olivines. We fail to see any petrographic distinction between the two rocks.

¹⁸ *Loc. cit.*, p. 99.

GEOLOGICAL AND CHEMICAL EVIDENCE.

In the discussion of the igneous rocks of the Washoe district we have confined ourselves mainly to a comparative lithological study of the rocks of the same mineral composition which have been classed by Mr. Becker as Tertiary and Pre-Tertiary eruptions, and have endeavored to show that they were identical masses presenting insensible gradations from the glassy to the granular structure. We have omitted for the most part the geological and chemical evidences, which not only strengthen the position we have taken, but clearly explain many difficult problems in the structural geology of the region and the relations of many of the rock masses to each other. It is a fact of some interest that nearly all geologists who have examined the district have been impressed with the apparent great variety in the igneous rocks represented. They have all easily recognized the more characteristic types, such as the granular rock which forms the bold front of Mount Davidson, the porphyritic rocks upon the flanks of the mountain variously designated as porphyritic diorite, propylite, and hornblende-andesite, and the glassy and fine-grained rocks mainly referable to pyroxene-andesite. But the moment they tried to outline their areas they were immediately beset with what seemed insurmountable difficulties. This is in part owing to the great amount of decomposition occurring in the neighborhood of the Comstock lode, but in greater part to the gradual transition in crystalline structure. Extreme forms were readily determined, but where to draw the line between them seemed impossible to decide.

The supposed differences between the porphyritic diorite and hornblende-andesite, which we can but regard as one rock, were so obscure as to make their determination one of great difficulty and led to a most confusing entanglement.¹⁹ That this confusion arose from superficial appearances produced by decomposition seems evident, the more decomposed forms being classified for the most part as the older rock. In his discussion of the hornblende-andesite, Mr. Becker says,²⁰ that through the decomposition of this rock "every variation in coarseness of grain also becomes apparent," and "all these changes tend to diminish the sharp definition of the porphyritic crystals and give the mass the look rather of an older dioritic porphyry than of a volcanic rock." Now, in speaking of the porphyritic diorite he says,²¹ "From some peculiarity either in composition or texture the porphyritic hornblende-diorites have undergone extensive decomposition" and only "two or three small masses" were found in a fresh state. From a study of these rocks it seems evident that the apparent coarseness of grain of most of the so-called porphyritic diorites is derived solely from the decomposition of

¹⁹ Geology of the Comstock lode, pp. 42, 87, 89.

²⁰ *Loc. cit.*, p. 58.

²¹ *Loc. cit.*, p. 39.

hornblende-andesite.²³ It is a most noteworthy fact that the decomposed forms of andesite occur in areas of fresh rock, while the somewhat fresh diorites are found in areas of general decomposition. The propylite of Baron von Richthofen and Mr. Clarence King for the most part belongs to this decomposed rock, the latter geologist remarking²⁴ "nearly all the propylite observed by us is decomposed." The distinguishing features of propylite were considered to be its high degree of crystallization and a certain characteristic habitus of the hornblende, the former closely relating it in structure to the hornblende-porphyrites, while the latter character tended to separate it superficially from the andesites with which it is unquestionably connected geologically. On the one hand we quite agree with Mr. Becker, who has ably shown after a rigid examination that a greater part of the propylite cannot be separated from the hornblende-andesite, and that there exists no evidence of its pre-andesitic eruption. He has clearly shown that the propylite of Washoe has no claim to be considered as an independent rock species, its change in habitus depending wholly upon decomposition. On the other hand our own work, showing the transition from glassy lavas to somewhat highly crystalline forms, compels us to agree with the earlier investigators, and to relegate his Pre-Tertiary porphyritic-diorite to the Tertiary hornblende-andesite. A comparison of the geological maps accompanying the works of Mr. King and Mr. Becker shows how embarrassing the difficulties were in drawing correct lines of demarcation between the supposed Pre-Tertiary and Tertiary masses. Over a very considerable part of the area they fail to agree. In general the latter geologist regards the south flanks of Mount Davidson as covered by hornblende-andesite, and the north flanks by diorite, the former geologist considering both north and south flanks as covered by propylite and of Tertiary age.²⁴

²³ The collection contains several series of specimens showing the various stages of decomposition of the rocks, classed as hornblende-andesite and porphyritic diorites. Among the former are numbers 486, 487, and 569 to 574. Among the latter, 448, 449, 451, 497, 498, 450, and 310, 311, 312.

²⁴ U. S. Geological Expl. of 40th Parallel, Vol. I, p. 557.

²⁵ In this connection it may be profitable to review the literature upon the propylite of Schemnitz in Hungary, a region which presents in many respects a close resemblance in its geological history to Washoe. Dr. Doelter (*Verhandlungen der k. k. geologischen Reichsanstalt*, 1879, p. 27), after a mineralogical and chemical study of the altered rocks recognizes the microscopical distinctions pointed out by Zirkel, especially in the quartzose rocks, but finds isolated masses which unite many of the characters of both andesite and propylite. He fails to find any difference in mode of occurrence or geological age between the two rocks. Vom Rath, probably after a study of the more crystalline portions, concludes that the propylite properly belongs to diabase and presents structural features quite unlike a Tertiary andesite. With his intimate knowledge of the Schemnitz region Professor Szabó, in the same number of the *geologischen Reichsanstalt*, from a geological standpoint denies the independent eruption of propylite. Dr. A. Koch, in a paper entitled "Neue petrographische Untersuchung der trachytischen Gesteine der Gegend von Rodna" (*Verhandlungen der*

The structure of the main body of the mountain is well brought out by the Sutro tunnel. It is shown to be for the most part a body of pyroxene-andesite extending from the central core of Mount Davidson, where it is well exposed, eastward to the outer foot-hills, where it is largely concealed by hornblende-mica-andesite, which breaks through it and covers the surface, the relations between the two rocks being well exhibited by the tunnel section. As already shown, there is a gradual and steady increase in degree of crystallization as we pass toward the central core, the pyroxene-andesite which forms the west country rock being one or two degrees coarser than the east country rock. In general the body west of the lode opposite the central portion of Mount Davidson is somewhat coarser than the rock to the eastward, but this does not hold true either to the north or the south. This is explained by the fact recognized by all geologists that the vein is situated along a line of great faulting, the displacement being quite sufficient to bring different portions of the same rock mass into juxtaposition. Along the line of the vein solfataric action has produced so much decomposition, especially to the eastward, that comparative petrographic studies of the walls is a matter of considerable difficulty. Nevertheless, the distance is so great and the exposures in the many tunnels so numerous that the evidence of identity of both walls seems conclusive. Let us consider, for example, a cross-section in one mine. On the 1,450-foot level of the Sierra Nevada mine a small body of pyroxene rock has been identified to the west of the main shaft, but to the east of the shaft the country rock is so decomposed that sufficiently fresh material for accurate identification was not obtained for 1,600 feet. At this point, where unaltered material occurs, it is shown to be a pyroxene rock. Now, although the rock has undergone so much alteration as partially to preclude specific identification, there is no evidence at hand that through-

k. k. geolog. Reichsanstalt, 1880, *Literaturnotizen*), is of the opinion that a separation of Grünstein-trachyte (propylite) from andesite is inadmissible, since he shows that both rocks are connected through transition forms. He points out that the principal difference between them is in the structure of the groundmass, the propylite being holocrystalline while the true andesite of Hungary always contains more or less glass. He maintains that the question whether there is any difference in geological age of these rocks is not yet satisfactorily determined. Dr. E. Hussak, in a purely petrographic paper, "Grünstein-trachyte oder Propylite," published in the same journal, states that the rocks are much decomposed and agrees with Zirkel as to their microscopical habits. He says: "Diese Gesteine ähneln den alten sogenannten Diäritporphyren wie auch den Diabas-porphyrten ungemein, sind jedoch mit den tertiären Eruptivgesteinen eng verknüpft und wohl nicht davon zu trennen." See also Prof. J. W. Judd's valuable paper "On the Ancient Volcano of the District of Schemnitz, Hungary," *Quar. Jour. Geol. Soc.*, August, 1876.

Unless erosion at Schemnitz, unlike the conditions at Washoe, has worn away the greater part of the superincumbent rock, we are led to believe, without any personal acquaintance with the district, that a thorough investigation of a large number of thin sections prepared from judiciously selected rocks would show a complete transition from the glassy volcanic lavas to those corresponding in texture to crystalline diorite or diabase.

out its whole length it was not originally a pyroxene-andesite. Wherever the rock occurs sufficiently fresh to allow a close study its identification with this type of andesite seems established. All these facts convince us that the Comstock lode cannot be considered as a contact vein between two different rock masses.

Owing to the intimate connection between hornblende and augite, and the fact that pyroxene-andesites with varying amounts of hornblende occur, indistinguishable from many hornblende-andesites with more or less pyroxene, it is impossible to draw a sharp line of demarcation between the two types. Great confusion arises when we undertake to map out the Washoe district, where both rocks occur in every possible gradation between the two specific types. Such transitions were recognized by Mr. Becker, who, having outlined the different areas covered by the different volcanic masses according to geological age, often considered himself forced to determine a rock quite as much from its occurrence within certain areas as from its mineral composition, regarding the variations as local modifications.

In general the hornblende-andesite here, as in many other districts, seems to be more silicious than the pyroxene types, yet analyses show many marked exceptions. In the intermediate volcanic rocks, like those which make up the greater part of the mass at Washoe, where the range in chemical composition between the two is so slight, a variation in mineral composition may easily take place.

Doubtless much of the confusion which exists in the Washoe district between the hornblende and pyroxene divisions of these rocks arises from the cutting of one rock by the dikes of the other in a far greater degree than has been heretofore recognized. Indeed, the region is penetrated by broad fissures and narrow dikes, varying in width from many hundred feet to those exposing only a few feet where cut by mining shafts and levels.

This is especially noticeable in the Sutro tunnel, which, after passing through the broad belt of hornblende-mica-andesite, enters, as has been already mentioned, a vast body of pyroxene-andesite forming the main rock mass as far as the tunnel runs. All other bodies, both large and small, cut by the tunnel present the appearance of occurring as dikes, many of them failing to reach the surface. These facts lend support to the theory that a large body of pyroxene-andesite forms the older and central mass of the mountain. At 17,100 feet from the mouth of the tunnel a remarkably fresh hornblende-andesite is cut with every indication, judging from the specimens, that it occurs as a dike. It seems quite possible that this may have served as a vent through which was extruded, a portion at least, of the hornblende rock found on the surface along the east base of Mount Davidson.

In the subjoined table are presented a series of twelve chemical analyses representing the principal variations in composition and structure of the volcanic rocks found at Washoe.

TABLE IV.—*Chemical analyses.*¹

Number.	Determination.	Locality.	SiO ₂	TiO ₂	Al ₂ O ₃	FeO ₂	FeO	MnO	CaO	MgO	Na ₂ O	K ₂ O	Other components.	Ignition.	Total.	Analyst.
I	Basalt	North of American Flat Creek.	47.91	2.70	14.26	1.45	7.80	trace	9.60	10.53	3.01	1.89	Li ₂ O trace	0.37 H ₂ O	100.02	Samuel L. Penfield.
II	Granular pyroxene-andesite.	Eldorado outcrop	56.71	.....	18.96	.....	6.45	.....	0.11	3.92	3.52	2.88	.....	1.94 H ₂ O	99.39	R. W. Woodward.
III	Pyroxene-andesite	Sutro tunnel, foot-wall, Savage connection.	56.40	1.14	15.99	3.26	3.82	0.12	6.98	3.64	3.33	1.91	P ₂ O ₅ .0.32	2.47	99.78	Gideon E. Moore.
IV	Hornblende-andesite.	Center of Cedar Hill Ridge.	58.55	0.83	15.48	3.93	2.07	0.11	6.44	3.60	3.99	1.60	P ₂ O ₅ .0.30	3.02	100.61	Do.
V	Pyroxene-andesite (hornblende bearing).	Ridge northeast of American Flat.	58.44	.....	18.17	.....	6.03	.....	6.19	2.40	3.20	1.97	CaO	2.87 0.76	100.63	W. G. Mixer.
VI	Pyroxene-andesite (hornblende bearing).	Silver terrace	59.22	.....	18.20	.....	6.60	.....	5.51	2.90	3.31	1.39	.....	2.80 H ₂ O	100.02	Do.
VII	Hornblende-andesite.	Cross Spur quarry below Graveyard.	60.82	.....	17.54	.....	5.42	.....	5.65	1.76	3.71	1.41	CaO	2.31	100.13	Do.
VIII	Hornblende-mica-andesite.	Mount Rose	63.80	.....	17.81	3.42	0.63	.....	5.12	2.07	4.27	2.26	Li ₂ O trace	0.88 H ₂ O	99.96	R. W. Woodward.
IX	Hornblende-mica-andesite.	Cross Spur quarry	63.13	.....	16.00	4.34	1.52	.....	4.45	2.07	3.87	2.65	.....	2.00 H ₂ O	99.54	Do.
X	Mica-andesite	800' east of Waller Defeat shaft.	65.66	0.98	15.87	1.78	1.25	.....	3.50	1.79	3.20	3.37	P ₂ O ₅ .0.23	3.10	100.75	Gideon E. Moore.
XI	Dacite	Spurnortheast of McClellan Peak near American Flat road.	69.96	.....	15.79	2.50	.....	.....	1.73	0.91	3.80	4.12	.....	1.53	100.07	F. A. Gooch.
XII	Rhyolite	South-southeast of McClellan Peak.	73.07	.....	11.78	2.90	.....	.....	2.02	0.99	1.19	6.84	.....	2.24	99.83	Do.

Number.	Designation in Mr. Becker's report.	Designation in Mr. King's report.	Number of thin section.	Number of specimens.	Designation in Mr. Becker's report.	Designation in Mr. King's report.	Number of thin section.	Number of specimens.
I	Basalt	Basalt	*526	22647	Hornblende-andesite	Propylite	*231	22717
II	Diorite	Diorite	(*) 18	22615	Later hornblende-andesite	Trachyte	*283	22631
III	Basalt diabase	.....	421	270	Mica-diorite	Trachyte	*264	22637
IV	Porphyritic diorite	.....	(*) 432	22719	Quartz-porphyr	.....	101	506
V	Angite-andesite	Hornblende-andesite	*632	22706	Quartz-porphyr	.....	496	251
VI	Angite-andesite	Hornblende-andesite	.....	.....	Quartz-porphyr	.....	495	249

¹ These analyses have been revised by comparison with the original records so far as possible; those which were found to be from much decomposed rocks have been omitted.

* The numbers marked with an asterisk are from the collection of the Fortieth Parallel Exploration; the remainder are from Mr. Becker's collection.

They are mainly compiled from the table published in Mr. Becker's monograph and revised as far as possible by comparison with the original records. They are here arranged according to their acidity in order to bring out forcibly the great similarity existing in chemical composition between rocks which we have endeavored to show were identical in mineral composition and structural features. Numbers I, XI, XII, the extreme basic and acidic varieties of the series, are now published for the first time. The identity in composition of the hornblende and pyroxene-andesites, which make up the central mass of the mountain, is shown in analyses II to VII, inclusive, the extremes in silica (with a variation of a little more than 4 per cent.) lying quite within the range of most volcanic extrusions. Between the coarse-grained rock from Eldorado outcrop (II), representing the mass of Mount Davidson, and the coarse-grained pyroxene-andesite (III) from the Sutro tunnel, near the Savage connection, chemical analysis fails to detect any marked difference; while between the so-called porphyritic diorite (IV) and hornblende-bearing pyroxene-andesites the variations are such as might occur in different parts of the same volcanic flow. In a well characterized hornblende-andesite from the Cross-Spur quarry (VII) the silica reaches 60.82 per cent.

In order to strengthen and confirm these analyses silica determinations have been made of several rocks from other localities in the district, carefully selected to represent the same range in mineral composition. Those agreeing in the preponderance of hornblende or pyroxene are placed together as follows:

1. Pyroxene-andesite (granular diabase), 56.40 per cent. SiO_2 .
2. Pyroxene-andesite (augite-andesite), 56.56 per cent. SiO_2 .
3. Hornblende-andesite (porphyritic diorite), 55.66 per cent. SiO_2 .
4. Hornblende-andesite (hornblende-andesite), 55.79 per cent. SiO_2 .
5. Hornblende-andesites (hornblende-andesite), 57.06 per cent. SiO_2 .

They all occur near the base of Mount Davidson from the following localities:

1. Ophir ravine, southeast of Cole water tunnel.
2. 1,000 feet due west of quarry above Occidental grade.
3. Ophir ravine, southeast of Cole water tunnel.
4. Ridge north of Ophir Hill, 150 feet west of old flume.
5. Tank 600 feet northwest of Yellow Jacket shaft.

From these it will be seen that the pyroxene-andesite from Ophir ravine is identical in silica percentage with the foot-wall, Savage connection in the Sutro tunnel, and differs from the pyroxene-andesite of the surface by only 0.16 per cent. of silica. The hornblende-andesite from near the Cole water tunnel differs from that of the ridge near Ophir Hill by 0.13 per cent. of silica. The refinements of chemistry like those of the microscope fail to detect any distinctions between the rocks of the same mineral composition, which have here been classed as Tertiary and Pre-Tertiary age.

We turn now to the later rock masses of both acidic and basic character found penetrating the main body of hornblende and pyroxene andesite of intermediate composition. We will first consider the hornblende-mica-andesites (later hornblende-andesite and mica-diorite), which, though presenting variations from a porphyritic lava with a glassy and microlitic groundmass to a granular structure recognized by the unaided eye, have already been shown to be indistinguishable petrographically. An examination of the specimens shows that it is the coarsely crystalline and decomposed middle-grained varieties which have been classed as Pre-Tertiary rocks, while the fresh and unaltered middle-grained and the glassy ones were regarded as of Tertiary age. The broad high ridge, lying to the eastward of Mount Davidson, of which Mount Rose and Mount Kate are conspicuous features, forms the principal mass of this rock breaking through the pyroxene-andesite. Upon the slopes of the ridge a considerable variation in texture of the rock is easily recognized. It is only on the surface along the ridge that glassy forms are met with. Comparing the hornblende-mica-andesite exposed through the 10,000 feet cut by the Sutro tunnel with the surface rocks, exact counterparts are observed with the exception that glassy forms are wanting. This is, however, what we should expect, and quite in accord with all the observations so far made upon the collections from Washoe, namely, that the glassy forms of the various rocks are only found at or near the surface, those from any considerable depth having cooled with sufficient slowness to become holocrystalline. Advancing now a step further we find that the more crystalline rock from this large body of hornblende-mica-andesite bears the closest resemblance to parts of the so-called Pre-Tertiary mica-diorite, which passes, as has already been shown, by imperceptible gradations into rock possessing a granular structure.

Let us consider in this place what the intermediate forms are which link together rocks of the chemical composition of a glassy hornblende-mica-andesite possessing all the characteristics of a surface lava with those having the structure of many granitic rocks. The results derived from a study of numerous rock sections²⁵ clearly indicate that the essential variation in the more porphyritic varieties takes place in the groundmass, which, starting with glass containing few microlites, gradually grows richer and richer in microlitic inclusions until only a small amount of glass remains as a cementing base. This in turn may be crystallized into microscopically cryptocrystalline particles. In a somewhat more advanced stage the cementing material assumes the appearance of uniformly oriented patches or of microcrystalline granitoid grains, which as the size of the grain increases is found to be partly quartz, partly feldspar. The dimensions of the cemented microlites also increase until they appear as small crystals embedded in a mass of ir-

²⁵ See Table III; also Table I.

regularly shaped grains of feldspar and quartz. As the number of large crystals and those of medium size increases the porphyritic appearance of the rock is lost, especially as the sharp outline of the larger crystals is no longer preserved, as already described. The character also of the feldspars changes by reason of the variation in their inclusions, those of glass growing less numerous as the rock becomes more crystalline, until they disappear entirely, occasional fluid inclusions making their appearance. When finally the grains are nearly all of one size the structure is the even granular one of a granite.

Quartz, which in the glassy forms of these hornblende-mica-plagioclase rocks occasionally is seen in small porphyritic grains, first makes its appearance as an essential ingredient among the microscopic grains of the groundmass, becoming more and more apparent as their size increases. This quartz contains in the coarser-grained forms numerous fluid inclusions, indicating that the gases disseminated through the magma, having been excluded by the first crystallizing minerals, were finally inclosed in the quartz, the last mineral to crystallize, which would necessarily occur when a magma consolidates under pressure, the gases being unable to escape. The number of mineral constituents is still further increased by the development of acidic feldspars, the uncrystallized material of which, together with the silica of the quartz, makes up the residual glass base of the vitreous forms of the rock. It has already been shown²⁶ that the glass of a vitreous lava grows richer in silica and alkalis as the more basic minerals crystallize out of the magma.

Thus the rock which in a vitreous state is composed essentially of basic feldspar, hornblende, and mica, with a groundmass of glass more or less full of microlites, is, when coarse-grained, formed of both basic and acidic plagioclase with some orthoclase, besides hornblende, mica, and quartz—the mineral composition of a quartz-diorite. The best examples of this decidedly granitic structure are from the 1,000-foot level of the Sierra Nevada and the shaft of the Lady Bryan mine, rocks which some geologists would call hornblende-bearing granite, but to which Mr. Becker refers in his monograph²⁷ as “fresh, coarsely granular, quartzose diorite.” Though we know but little of the actual occurrence and field relations of the rocks represented by these two specimens, one coming from the end of a drift and the other collected from the dump of a mine, still it is noteworthy that they both come from the immediate neighborhood of the most extensive area of hornblende-mica-andesite in the district, and though geological evidence of their direct connection is wanting, the chain of petrographic evidence is so complete as to leave no doubt in our minds that these coarsely granular rocks are parts of

²⁶ F. Fouqué, “Santorin et Ses Éruptions,” Paris, 1879, p. 11. Hague and Iddings, “Notes on the volcanoes of Northern California, Oregon, and Washington Territory,” *Am. Jour. of Science*, Vol. XXVI, Sept., 1883, p. 230.

²⁷ *Geology of the Comstock Lode*, page 192.

the same magma as the hornblende-mica-andesites which have crystallized very slowly under considerable pressure.

With the exception of one body near the north end of the vein, the so-called mica-diorite only occurs on the surface, as shown on the map,²⁸ in a few isolated patches of no great elevation, where it presents the appearance of having broken through the andesite. That there is good reason for such a conclusion is borne out by the strongest geological evidence beneath the surface. It has been pointed out that the andesite of the Sutro tunnel is cut in three places by narrow dikes of hornblende-mica-andesite of a medium crystallization, showing that here at least a similar rock is younger than the main body of Tertiary andesite.

Other instances of this hornblende-mica-rock cutting the pyroxene-andesite are shown in the vertical sections through the Yellow Jacket and Belcher mines (atlas sheet VII), and can only be reasonably explained as dikes and offshoots from the main body of a later rock penetrating an older one. By reference to the geological map it will be seen that the Forman shaft is located in andesite between two small outcrops of hornblende-mica-rock only 3,500 feet apart. Now the fact that the shaft has been sunk for a depth of 2,340 feet without encountering either body seems to point to the conclusion that these hornblende-mica rocks are simply dikes cutting the andesite.

Let us consider one more fact. On the 1,950-foot level of the Utah mine a narrow body of medium-grained hornblende-mica rock is exposed penetrating the pyroxene-andesite. Now this small body is vertically beneath the later hornblende-mica-andesite of the surface, with the evidence all tending to the conclusion that the two bodies are closely connected masses.

Such geological evidence as to the position of these rocks seems all-sufficient to determine their age, but taken in connection with the proof of identity afforded by rigid petrographic analysis the arguments appear indisputable.

As already mentioned, the hornblende-mica rocks vary considerably in their mineral composition within certain limits, and a corresponding variation is observed in their chemical composition. Analyses VIII and IX (Table IV) are from the hornblende-mica-andesites of Mount Rose and Cross Spur quarry, which are rich in iron magnesia silicates, hornblende being in excess of mica in one case and equaling it in the other. Analysis X from the "mica-diorite," 800 feet east of the Waller Defeat shaft, shows less iron and magnesia, which corresponds to the small amount of iron and magnesia silicates found in the rock, mica greatly predominating over hornblende. It represents one of the most acidic of these hornblende-mica rocks.

The quartzose Tertiary rocks, as has been shown, belong both to dacite and to rhyolite, the rocks intermediate between the two being

²⁸Geology of the Comstock Lode, Atlas, Sheet IV.

well developed. The surface area covered by them lies wholly in the southern and southeastern portion of the district, mainly in the neighborhood of American Flat. Their geological position is best observed in the underground workings to the north, where the main body of pyroxene-andesite occupies the surface, and although the number of exposures is limited, their evidence is clear. No stronger proof can be desired of the Tertiary age of the rocks in question than the occurrence in the Sutro tunnel of a broad dike, 1,400 feet in width, with numerous offshoots cutting the main body of pyroxene-andesite. Microscopical examination proves this rock to be the counterpart of a lithoidal variety found on the surface near Gold Cañon and the Red Jacket mine.²⁹ In the Overman mine a dacitic or rhyolitic rock apparently occurs as a narrow dike extending upward nearly to the surface from the 2,000-foot level. Again the occurrence in the Belcher mine can best be explained on the simplest and most plausible theory of an offshoot or stringer from the main mass. The Forman shaft, after passing through pyroxene and hornblende-andesite, exposes at about 2,340 feet from the surface a small body determined by Mr. Becker as an orthoclase rock, which he classes as quartz-porphyry. Although our knowledge of the body is extremely limited, there seems to be every reason, judging from analogy, that it also occurs as an intrusive mass penetrating the andesite but failing by many hundred feet of reaching the surface. It is worthy of note that the rock is holocrystalline and presents certain characteristics common to igneous rocks cooled at considerable depths below the surface, and which many geologists regard as evidence of their Pre-Tertiary age.

A recent analysis in the laboratory of the United States Geological Survey, by Dr. F. A. Gooch, of a dacite from near McClellan Peak, is given in Analysis XI (Table IV). It will be noticed that the potassa is but slightly in excess of the soda, and the microscope shows that the plagioclase is far in excess of orthoclase among the porphyritic crystals. In Analysis XII, also by Dr. Gooch, the potassa greatly predominates over soda, and the rock from which it was made is characterized by prevailing orthoclase, the habitus and chemical composition being those of a typical rhyolite.

Geological evidence having proved that the rock penetrated by the black dike is inseparable from the Tertiary pyroxene-andesite lavas, it of course follows that the later rock is also of Tertiary or still more recent age. A comparative study of the hand specimens and their sections has shown the similarity in composition and structure existing between the surface basalts, near American Flat, and the well-known black dike of the Comstock lode, they differing only slightly in degree of crystallization and state of preservation. By reference to the map (atlas sheet IV) it will be noticed that there are only five surface

²⁹ Compare the following hand specimens: Numbers 182 to 192 from the Sutro tunnel with 417, 370, 397, 399, 405, and 411 from the surface collection.

occurrences of basalt, all of them insignificant in area and in height. In a direct line from the basalt masses, immediately to the westward of American Flat, it is only 4,500 feet to the Caledonia shaft, where the black dike is last seen along the line of exploration on the Comstock.

The chemical composition of the surface basalt is given in Analysis I (Table IV). It is somewhat basic, but in other respects is quite similar to many of the basalts of the Great Basin. The basalt of the black dike from the Belcher mine, 1,145 feet below the surface, yielded 49.79 per cent. of silica, the difference between the two analyses being quite within the range of variation for the same flow. Now, although the black dike forms the only dike of basalt known in the district, and its direct connection with the small surface patches has never been traced, the evidence is quite sufficient to lead to the conclusion that it, like the intrusive bodies of hornblende-mica-andesite, dacite, and rhyolite, is an offshoot from a much larger mass at no great distance.

CONCLUSIONS.

As stated in the first part of this paper our investigation leads us, in many important particulars, to conclusions in respect to the geological structure of the Washoe district quite at variance with the opinions held by our predecessors. Throughout the body of the paper we have endeavored to place before the reader with considerable detail the facts upon which our opinions were based. Let us then in reviewing these results state in a few words what we consider to be the geological history of Washoe and the relations of the principal rock masses and intrusive bodies to each other, and then briefly summarize the conclusions maintained in this discussion as to the development of crystallization in the igneous extrusions which have built up this mountain pile.

We regard the main mountain mass of which Mount Davidson is the culminating peak to be formed of both pyroxene- and hornblende-andesites, of much the same ultimate chemical composition, analyses showing a variation of only 4 per cent. in silica. Both these types of andesite are so intimately connected geologically with each other as to render it extremely difficult to separate them on a basis either of physical structure or of geological age. So long as the conditions under which hornblende and pyroxene are formed in lavas of this class are so little understood it becomes a difficult matter at Washoe to determine with precision the relations of andesitic eruptions based solely upon these minerals. The fact, however, that the main mass of Mount Davidson is made up of coarsely crystalline material originally a pyroxene rock, and that the section through the Sutro tunnel after leaving the hornblende-mica-andesite body of Mount Rose and Mount Kate runs mainly through pyroxene-andesite, makes it highly probable that the

earlier and larger part of the eruption was composed of this rock. Through this pyroxene-andesite hornblende-andesite is known to penetrate, and observations all point to the conclusion that vents have been opened through which both types of rock have been forced upwards, although not necessarily reaching the surface.

After these eruptions of pyroxene and hornblende andesites there was a period of rest, during which there was more or less removal of the superficial material by denudation, a study of the surface geology presenting many arguments in favor of a time of comparative inaction. These older andesitic rocks have been broken through by numerous intrusive bodies of both acidic and basic lavas represented by hornblende-mica-andesites, dacites, rhyolites, and basalts. From masses of these later rocks offshoots were pushed out and forced upwards into the older rocks, in many cases failing to reach the surface, but now exposed by vertical shafts and horizontal workings.

We find the glassy forms of these rocks only on or near the surface. Rocks from the tunnels and mining shafts from any considerable distance beneath the surface present invariably a holocrystalline structure, while the more coarsely crystalline forms come from near the central mass, from intrusive dikes, or are brought up from the lowest depth reached by mining shafts. It is not of course to be expected that development in crystallization should show an unvarying increase in any given direction through a rock mass. On the contrary, changing conditions would necessarily bring about more or less local modifications. Variations in rapidity of cooling or amount of pressure would produce local centers of crystallization, with corresponding variations in rock structure. Moreover the degree of crystallization developed in different lavas under similar conditions appears to depend upon their chemical composition, the basic lavas showing a greater tendency to crystallize than the acidic.

When we consider the evidence offered by the 4 miles of the Sutro tunnel, the vertical sections 3,000 feet in depth, and the network of long galleries run at different levels from the main shafts, the innumerable facts, all pointing in one way, present such overwhelming proof that we are led to the conclusions maintained in this paper, and briefly summed up as follows:

That the degree of crystallization developed in igneous rocks is mainly dependent upon the conditions of heat and pressure under which the mass has cooled and is independent of geological time.

That there are abundant geological and petrographic evidences in the Washoe district to show that the igneous rocks do not belong partly to Pre-Tertiary and partly to Tertiary eruptions, but are all of Tertiary age.

That the so-called granular diorite and diabase, augite-andesite are identical and belong to the same geological body.

That the so-called porphyritic diorite is identical with hornblende-andesite and should be designated by the latter name.

That the so-called mica-diorite is identical with the later hornblende-andesite and both rocks are of the same geological age.

That the quartz-porphyry is of Tertiary age and resolves itself into both dacite and rhyolite.

That the later diabase or black dike and the basalt are one and the same rock, the difference being that the former is only known as a narrow dike while the latter occurs in flat-topped bodies and low hills on the surface.

That the Comstock lode occupies a fissure along a line of faulting in rock of Tertiary age, and cannot be considered as a contact vein between two different rock masses.

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DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 18

ON MARINE EOCENE FRESH WATER MIOCENE AND OTHER
FOSSIL MOLLUSCA OF WESTERN NORTH AMERICA

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

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[Bulletin No. 20.]

The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavo. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization. And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. iv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xii, 478 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, and VIII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt., U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price \$10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Beeker. 1882. 4°. xv, 423 pp. 7 pl. and atlas of 21 sheets folio. Price \$11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price \$1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price \$1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price \$1.05.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price \$1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price \$1.10.

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The following are in press, viz:

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. ix, 238 pp. 35 pl.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 56 pl.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. —, — pp. 46 pl.

The following are in preparation, viz:

I. The Precious Metals, by Clarence King.

Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.

Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

Lake Bonneville, by G. K. Gilbert.

Sauropoda, by Prof. O. C. Marsh.

Stegosauria, by Prof. O. C. Marsh.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 18 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Angitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 43 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coinage value of Troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30', from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752-1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. A Report of work done in the Washington Laboratory during the fiscal year 1883-'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thimolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 125 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Dr. C. A. White. 1885. 8°. 23 pp. Price 5 cents.

16. On the higher Devonian Faunas of Ontario County, New York, by J. M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

17. On the Development of Crystallisation, etc., by Arnold Hague and J. P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Dr. C. A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

Numbers 1 to 6 of the Bulletins form Volume I, and numbers 7 to 14 Volume II. Volume III is not yet complete.

The following are in press, viz:

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. — pp. 1 pl. Price — cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. — pp. 5 pl. Price — cents.

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22. On New Cretaceous Fossils from California, by Charles A. White, M.D. 1885. 8°. — pp. 5 pl.
Price — cents.

STATISTICAL PAPERS.

A fourth series of publications having special reference to the mineral resources of the United States is contemplated.

Of that series the first has been published, viz:

Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 513 pp. Price 50 cents.

The second volume of this series, Mineral Resources 1883 and 1884, is in preparation and will soon be put to press.

Correspondence relating to the publications of the Survey, and all remittances, which must be by POSTAL NOTE or MONEY ORDER, should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C.

WASHINGTON, D. C., May 25, 1885.

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J. W. POWELL DIRECTOR

CONTRIBUTIONS

TO THE

MINERALOGY OF THE ROCKY MOUNTAINS

BY

WHITMAN CROSS and W. F. HILLEBRAND



WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

LETTER OF TRANSMITTAL.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE ROCKY MOUNTAINS,
Denver, Colo., March 1, 1885.

SIR: I have the honor to transmit herewith a paper by Messrs. W. Cross, assistant geologist, and W. F. Hillebrand, chemist, representing work that has been done by them in the office and laboratory of this division, at intervals of leisure from their regular duties, during the past three years. Believing that the results of their investigations form a valuable contribution to the mineralogy of the Rocky Mountains, I would respectfully suggest that they be published in the form of a bulletin, so that they may be made immediately available to those interested in this science.

Very respectfully, your obedient servant,

S. F. EMMONS,
Geologist in Charge.

Hon. J. W. POWELL,
Director United States Geological Survey.

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CONTRIBUTIONS TO THE MINERALOGY OF THE ROCKY MOUNTAINS.

By WHITMAN CROSS and W. F. HILLEBRAND.

INTRODUCTORY REMARKS.

A large part of the subject-matter contained in the following pages has already appeared in print, at various times during the past four years, in the *American Journal of Science* or the *Proceedings of the Colorado Scientific Society*. As opportunity has offered, the studies have been extended upon the old or upon new and better material, so that much of that which has been previously published is here presented in a revised or enlarged form. The desirability of collecting in one place the notices of minerals from the same general region has led to the reproduction of some descriptions unaltered.

The more purely mineralogical parts of Sections I and II, for which the first-named author is chiefly responsible, does not claim to be so thorough and exact in many cases as the nature of the material may render desirable. This is partially explained by a want of the proper instruments for use in determining certain optical and physical properties of the minerals, but still more fully by the fact that the geological investigations in progress have left but little time for pure mineralogy.

In regard to the chemical part of the work a few remarks are necessary. From the first establishment of a laboratory in Denver a special aim has been to make the analytical work as thoroughly accurate as possible even though the amount accomplished should in consequence be lessened. As the main part of the laboratory work consists in investigations upon eruptive rocks, an exact knowledge of whose composition is at present deemed of great importance, it was sought to reduce the errors ordinarily incident to analyses of such rocks to the smallest possible limits. To this end none of the ordinary reagents employed in any quantity are used without being first subjected to careful analysis. If they are found to contain sufficient impurity to influence even to a slight extent the result of an analysis, they are either rejected altogether or purified, or the percentages of impurities present are estimated and deducted from each analysis, for which weighed or measured quantities of these reagents are employed. Thus the very small quantities of

silica, ferric oxide, alumina, and lime, almost invariably to be found in the purest of sodium carbonate, in a measure due to dust that has collected in the process of manufacture and packing, and which will generally influence the result of an analysis from 0.1 to 0.2 per cent., are allowed for. Ammonia, which, after being kept in carboy for some length of time, often contains large amounts of silica and other foreign matter, is redistilled and collected in pure water every few weeks.

By taking such precautions and using wherever possible platinum vessels, with proper care a high degree of accuracy is attainable. Especially is this so when no solid reagents enter into an analysis, as in the case of zeolites, of which a large number of analyses appear on subsequent pages and in few of which the sum total of percentages exceeds 100.1. A long series of analyses of eruptive rocks has been made in which, during the past two years, it has been the rare exception for an analysis to foot up over 100.2.

Without these explanatory remarks the close approximation to 100 per cent. shown by so many analyses might rather inspire distrust than confidence.

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I.—MINERALS FROM THE BASALT OF TABLE MOUNTAIN, GOLDEN, COLORADO.

By WHITMAN CROSS and W. F. HILLEBRAND.

DESCRIPTION OF TABLE MOUNTAIN.

Table Mountain is a plateau or *mesa* with an area of from 4 to 5 square miles, situated upon the border of the great plains, 12 miles west of Denver, approaching so closely to the abruptly rising foot-hills, composed of Archæan rocks, that the intervening space is not more than 1 mile in width. Within this space, however, are exposed the upturned edges of strata of the Triassic, Jurassic, and Cretaceous ages, including in the latter the coal-bearing Laramie formation, all dipping steeply eastward. The mountain owes its existence to a sheet, or rather, in most places, to two sheets of basalt, which have in a measure protected the underlying soft Tertiary beds from erosion, which has removed the upturned Mesozoic strata to the west, until a valley several hundred feet deep has resulted, separating Table Mountain from the foot-hills. The Tertiary strata below the basalt are horizontal, and seem at first glance unconformable with the Mesozoic, but this is largely due to the location of the valley of erosion in a sharp fold; in other places apparent conformability is shown.

Clear Creek issues from the foot-hills opposite the mountain, and has cut a gorge directly through it, dividing it into what are known as North and South Table Mountains, which have an average elevation above the creek bed of about 700 feet. On the banks of the creek behind the mountain is situated the town of Golden.

The source of the basalt is in certain dikes situated to the north and northwest, whence the lava spread out in sheets and flowed to the south-southeast. The lower sheet averages 100 to 115 feet in thickness and possesses the structure of a stream which has flowed upon the surface. Adjacent to the underlying strata is a layer of a very porous structure about 1 foot in thickness, then follows massive compact rock for 70 feet, while the upper 40 to 50 feet show many cavities, large and small, more or less flattened and drawn out, and the surface is rough and jagged. The first sheet was covered by a second, of identical composition, before erosion or decomposition had produced noticeable effects.

Of the second sheet only the massive lower part remains, and its thickness, as well as the lateral extension of both sheets, can only be a matter of conjecture. The rock is a feldspar basalt of very simple composition, rather coarsely crystalline in its massive parts, and in the porous part with a groundmass which becomes finer grained as it approaches the contact or the surface. A glassy base, now much devitrified, was formerly present in the porous parts.

In the cavities of the upper portion of the lower sheet are many beautifully crystallized zeolites, associated with calcite and aragonite. The mode of occurrence varies somewhat in different parts of the mountain, and a few species seem to be locally restricted, but most of those to be described can be found in abundance and well developed.

At a point on the southern face of North Table Mountain, where the greatest number of species occur together, the students in the School of Mines at Golden began blasting for specimens several years ago. During the present investigations the locality was still further opened and absolutely fresh and clear material was obtained.

The only previous notice of this mountain is embodied in the report of Arch. R. Marvine, in the Annual Report of the United States Geological and Geographical Survey of the Territories for the year 1873, pp. 129-131, but the information given is exceedingly meager and in part incorrect.

The Survey is indebted to Prof. A. Lakes, of the School of Mines, for calling special attention to Table Mountain.

MANNER OF OCCURRENCE OF THE MINERALS.—The following mineral species have been identified in the cavities of the basaltic sheet, viz.: analcite, apophyllite, chabazite, levynite, thomsonite, mesolite, natrolite, scolecite, stilbite, laumontite, calcite, and bole. Of the occurrence of these species a few remarks will be in place before proceeding to detailed descriptions.

Primarily one can distinguish between the minerals occurring in fissures and those in the roundish cavities of the amygdaloidal zone. On both mountains are many fissures and irregular cavities having outward communication, in which calcite, bole, and reddish zeolites are almost always deposited. Occasionally colorless zeolites (analcite or natrolite) appear in fissures, but it is much more characteristic to find them in the closed cavities. On the other hand a reddish, horizontally stratified zeolitic deposit is found in many amygdaloidal cavities, filling the smaller ones completely or forming a floor in the larger ones. As the minerals developed here are in part the same as those found in adjacent fissures, and as these reddish deposits always precede in time the formation of the colorless zeolites, it seems probable that all the cavities containing the minerals in question were formerly penetrated by fissures. Some such explanation is necessary, for cavities containing the reddish zeolites occur side by side with those in which only members of the other group are present. In some few cases, small fis-

tures, now filled, were found leading into cavities containing the stratified deposits.

The zeolites are then naturally divisible into two groups, according to mode and time of formation, the first containing laumontite, stilbite, and thomsonite; the second, stilbite and thomsonite, with all the other species of the above list. They will be thus considered in the following description.

ORDER OF DEPOSITION.—Considering all the species which occur in associations allowing inferences as to relative age, the following may be given as the order observed, beginning with the oldest:

- | | | |
|--------------------------|---|-------------------|
| 1. Laumontite. | } | Red or yellowish. |
| 2. Stilbite. | | |
| 3. Thomsonite. | | |
| 4. Calcite (yellow). | | |
| 5. Stilbite. | | |
| 6. Chabazite. | | |
| 7. Thomsonite. | | |
| 8. Analcite. | | |
| 9. Apophyllite. | | |
| 10. Calcite (colorless). | | |
| 11. Mesolite. | | |

Chabazite and thomsonite were also formed again in very small quantity, probably between 9 and 10. Natrolite, scolecite, and levynite do not occur in direct association with most of the above, so that their places in the series are unknown.

ZEOLITES. FIRST GROUP.

GENERAL.—The minerals of this group are best developed in the stratified deposits of the amygdaloidal cavities, where also the order and manner of deposition can most clearly be seen.

In a large cavity containing a floor of the reddish-yellow mixture of the minerals of this group, it is at once noticed that the roof and sides above the level of the stratified mass show no trace of any one of these species. From this fact and from the structure of the mass the inference is warranted that the formation began at the bottom and proceeded very rapidly to its close. Usually the lower portion of such masses is composed of a reddish-yellow mineral in irregular grains, forming a compact aggregate in which lie isolated spherules of a similarly colored radiate mineral. These spherules are seldom more than 2nd in diameter and are very perfect spheres. They increase in number upward and finally compose the greater part of the deposit.

In one cavity, 6 to 8 feet in horizontal diameter and about 2 feet in height, the deposit is quite different. Here the main mass is loosely granular, and is formed chiefly by a bright greenish-yellow mineral, while a stratified appearance is produced by layers of a white or colorless substance.

Some of the light layers are chiefly made up of easily recognizable stilbite, and the same mineral in distinct tablets forms the upper layer of the whole deposit. There are also irregular seams of white running through the yellow material.

LAUMONTITE.

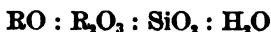
DESCRIPTION.—If the loose sand from the above-mentioned cavity be placed under the microscope with a power of about 15 diameters, it is seen to consist of prismatic grains, mostly with broken terminations. Many of the grains are clear and transparent, with the greenish-yellow color mentioned, while others are dull. The clear prisms polarize strongly, and extinction upon a prismatic plane takes place at an angle of 35° to 40° with the vertical axis.

On splitting open some of the white layers, surfaces are obtained showing minute stout prismatic crystals, which seen under the microscope present the same habit as the yellow grains. The prism angles are nearly 86° and 94° , and the termination is usually formed by an oblique plane, like a hemidome of the monoclinic system. The optical orientation is the same as in the yellow crystals and corresponds also to the requirements of the monoclinic system so far as can be determined. The properties given agree with those of laumontite, and in the light of the chemical analyses the identification of both yellow and white crystals with that mineral seems entirely justifiable.

CHEMICAL COMPOSITION.—The analysis gives the following results:

	I.—Yellow grains.	II.—White crystals.
SiO ₂	51.43	52.07
Al ₂ O ₃	21.52	21.30
Fe ₂ O ₃	0.94	.....
CaO.....	11.88	11.24
K ₂ O.....	0.35	0.42
Na ₂ O.....	0.19	0.48
H ₂ O.....	13.81	14.58
(W. F. Hillebrand.)	100.12	100.09

Oxygen ratios:



I. 1 : 2.97 : 7.83 : 3.50

II. 1 : 2.94 : 8.15 : 3.81

(In all calculations of ratios 27 is taken as atomic weight of Al.)

These analyses represent the composition of air-dried material, and the percentages were calculated from the analyses published in the

American Journal of Science.¹ The latter were made after drying over sulphuric acid, it having been observed that at 100° C. an unexpectedly large loss took place, steadily increasing as the temperature rose above 100°. Even when simply dried over sulphuric acid the loss in the case of I was 0.60 per cent., and in the case of II was 1.45 per cent. These abnormally large losses, coupled with still larger ones observed subsequently in analyzing other zeolites, seemed to indicate that all, or at any rate nearly all, the water removed by sulphuric acid should be counted with the water of crystallization, especially as when this was done the oxygen ratios generally more nearly approached that required by theory; for example, in II the ratio for material dried over sulphuric acid is only 1 : 2.94 : 8.15 : 3.42, instead of 1 : 2.94 : 8.15 : 3.81 as above given. Recent investigations by Jannasch² on heulandite and epistilbite tend to confirm us in this opinion.

The ratio of II agrees fairly well with the theoretical requirements of laumontite, 1 : 3 : 8 : 4, especially as it can hardly be supposed that the material was absolutely pure. It is quite probable that a small amount of stilbite was included with the material analyzed, which would explain the rather high value for SiO₂.

In regard to the amount of water found it is only necessary to suppose that the dull particles have lost a part of their water while the transparent grains are entirely fresh in order to explain the relation of water to the other constituents as shown in the above ratios, a supposition in full accord with the characteristic tendency of laumontite to lose its water on exposure.

The mineral is not quite so easily fusible before the blow-pipe as typical laumontite should be according to the text-books, but the difference is not sufficiently pronounced to be considered abnormal.

MIXED ZEOLITES.

GENERAL DESCRIPTION.—Turning now to the more compact reddish-yellow deposits, which correspond so closely to the one described above, the same constituent minerals were sought for. Some small cracks or fissures were noticed, usually ending blindly in the yellow mass, some of which were only partially filled with minute white crystals. On splitting the mass open along such a half-filled crack two surfaces were obtained, coated with minute but exceedingly perfect clear crystals, easily recognizable under the microscope as laumontite and stilbite. The little crystals of the former show occasionally the clinopinacoid and a steep positive orthodome in addition to the prism and base.

¹ III, Vol. XXIII, p. 135.

² Neues Jahrbuch für Mineralogie, etc., 1884, II, 206.

The sand obtained by simple fracture of the yellow massive portion on being placed under the microscope is seen to consist largely of fragments of tabular crystals, the angles of which, so far as they are determinable, correspond to stilbite. The grains which are not evident fragments of tablets are in part roughly prismatic, though seldom showing definite faces; neither could the optical action be satisfactorily determined.

CHEMICAL COMPOSITION.—Chemical analyses were made from two different specimens of the yellow granular mass, care being taken to exclude all reddish spherules. The results are given under III and IV below.

	III.	IV.
SiO ₂	54.20	53.87
Al ₂ O ₃	17.26	17.26
Fe ₂ O ₃	0.77	0.74
CaO.....	8.35	8.27
K ₂ O.....	0.17	0.07
Na ₂ O.....	1.88	1.48
H ₂ O.....	18.09	18.44
	100.22	100.13

(W. F. Hillebrand.)

Oxygen ratios:



III. 1 : 3.01 : 10.43 : 5.80

IV. 1 : 3.03 : 10.42 : 5.95

Analyses III and IV were published in the American Journal of Science, with this difference, that they represented the composition of dried material. Inasmuch as III lost 2.14 per cent. of moisture in two days over sulphuric acid (no further loss in three days) and IV 1.69 per cent. under similar conditions, the whole is counted as water of crystallization for the reasons given in discussing the analyses of laumontite.

As will be seen later, pure crystals of colorless stilbite from Table Mountain do not possess, as regards SiO₂ and H₂O, quite the theoretical composition of that mineral (see analysis VI, p. —). If, however, that analysis represents the composition of all stilbite from this locality, these analyses III and IV correspond remarkably well to mixtures of much stilbite with a little laumontite, as was surmised from microscopical examination of the material.

It seems remarkable that the material from two different cavities should contain the two minerals in so nearly the same proportions as is indicated by the analyses.

THOMSONITE SPHERULES.

CHEMICAL IDENTIFICATION.—Concerning the reddish spherules no data of importance could be obtained except by chemical analysis.

Under V is given the composition found for this substance in material which was apparently very pure.

	V.
SiO ₂	40.53
Al ₂ O ₃	29.23
Fe ₂ O ₃	0.79
CaO.....	12.43
Na ₂ O.....	4.31
H ₂ O.....	12.79
(W. F. Hillebrand.)	100.06

The oxygen ratio for this is:



$$1 : 3.00 : 4.63 : 2.44$$

These figures agree so well with those obtained for the colorless thomsonite (see page 25) that in the absence of anything to the contrary the identity of the two substances can scarcely be doubted. It was noticed here, as in the other thomsonite, that about 2 per cent. of the water could be expelled only at a very high temperature. The ferric oxide in all these minerals seems to replace a portion of the alumina.

Thomsonite in the form of these reddish spherules has been deposited locally in great abundance in irregular cavities on the upper surface of the lower sheet of basalt and also in the angular spaces formed where the scoriaceous crust of the flow has been broken or crumpled. It is here deposited alone, free from stilbite and laumontite, but the spherules are exactly similar in size and appearance to those formed in the cavities below.

ZEOLITES. SECOND GROUP.

STILBITE ("DESMIN" GERMAN).

GENERAL.—As has been already mentioned, stilbite occurs occasionally in clear, colorless crystals, as well as in the manner characteristic of the first series. It is noteworthy that in all such cases as yet observed the clear stilbite is either deposited upon the colored zeolites of the group described, or in close proximity to them, although it may be associated with chabazite or clear thomsonite, species having no such limitation. When these three minerals are associated it is sometimes difficult to assign an order of deposition, as they seem to have been nearly contemporaneous. The tablets of stilbite are usually attached by an edge, projecting at various angles from the underlying surface, and rarely appear so abundantly as to form a crust.

CRYSTAL FORM AND OPTICAL PROPERTIES.—The largest crystals seen measure about 1.5^{cm} in longest diameter and 2.3^{mm} in thickness,

These crystals, however, are made up of several plates, which are not in exactly coincident orientation, and their surfaces are not very smooth or glistening, from which causes they are not available for either crystallographical or optical studies. For these purposes only the minute transparent tablets which are occasionally found intermingled with the others could be used.

These tablets have the usual rhombic symmetry which has been explained by von Lasaulx as the result of a double twinning of a monoclinic groundform isomorphous with those of harmotome and phillipsite, and according to the laws observed in those species. The isomorphism thus pointed out has been advocated from the chemical side by Fresenius.³ The Table Mountain stilbite presents some structural and optical properties not fully in accord with the statements of von Lasaulx, and yet the material is not perfect enough to show the full significance of the disagreement. A description of the observed variation may lead to an explanation based upon the study of other and better material.

Assuming the isomorphism stated, the predominant face is $\infty P \pm$, while ∞P and $0 P$ are always present, and $+ P \infty$ occasionally. The front prism angle was measured at $118^\circ 22'$, by attaching small flakes of mica to the dull surfaces of a large crystal, while approximate measurements in the othodiagonal zone could be made under the microscope.

For optical examination a number of small tablets were mounted in balsam, lying upon the predominant pinacoidal face; others were mounted in the same position after a little grinding, which was intended simply to remove impurities from the surface. All exhibit the same optical action. The larger crystals could not be used for the reasons stated above.

Fig. 1 of the plate represents the structure described by von Lasaulx⁴ in crystals examined by him, the figure being copied from his article, with a simple inversion to correspond with Figs. 2 and 3. On examining a crystal of tabular form, mounted as above described, between crossed nicols, there appears a division into four quadrants, $a a$ and $b b$, by lines passing through the centre parallel and normal to the clino-axis. By parallel position of these lines with the principal sections of the nicols all four portions appear equally dark, but the maximum of extinction is only obtained by a revolution of about 5° from this position, for two diagonally opposite quadrants when the revolution is to the right, for the other two when to the left. There is therefore a difference of about 10° in extinction of adjoining quadrants. According to von Lasaulx the bisectrix is inclined 5° to the clino axis, while the optical normal makes an angle of 34° with the vertical axis. Reference will be made to this point later. A distinct zonal structure parallel to the outlines of $0 P$, and ∞P is described, and a very faint subdivision of

³Zeitschrift für Krystallographie, III, 42, 1878.

⁴"Ueber den Desmin." Zeitschrift für Krystallographie, II, 576, 1878.

each quadrant by this zonal structure is mentioned, but it is distinctly stated that no corresponding optical division exists. It is noted, however, that in a given quadrant the extinction adjoining d may be slightly less than that near c . Aside from this division into quadrants, which is in agreement with the supposed symmetry and twinning of the mineral as isomorphous with harmotome and phillipsite, there are often four other fields, $c c$ and $d d$. The portions $c c$ are diverging bundles of a somewhat fibrous, colorless mass, producing in all positions brilliant aggregate polarization. The parts $d d$ are made up of bars placed perpendicularly to the line of OP , the area thinning out wedge-like toward the centre. Sections situated in the orthozone show coincident extinction throughout, so that these irregular aggregates (c and d) seem to consist of stilbite substance having at least the orthoaxis in common with the rest. In all the many occurrences examined by von Lasaulx this division is more or less distinct. The portions c and d , termed by him "inverse substance," in contrast to the normal quadrants a and b , sometimes predominate largely, while d at least is occasionally very subordinate. With this action as given by von Lasaulx will now be compared that exhibited by the Table Mountain stilbite.

Fig. 2 represents the optical behavior of a crystal from Table Mountain, and is typical of that in all examined. It is in parallel position with Fig. 1, the dome $+ P \infty$ being added while at one end is a repetition of ∞P and $P \infty$. The same primary divisions are here seen as in Fig. 1, but each quadrant, a , is clearly subdivided when seen in polarized light by the zonal structure, which in the octants a and b runs parallel to the outline of ∞P , in a' and b' parallel to OP . The two systems meet in an irregular line which usually runs from the angle between OP and ∞P to the centre of the crystal. The bands of the two systems do not cross each other, as represented in Fig. 1, and a very small but appreciable variation in optical orientation may be seen. The direction of extinction in a' and b' measures about $4^\circ 15'$ from the edge of OP , while in a and b it is 5° – $5^\circ 30'$ from the same direction. This corresponds to the statement of von Lasaulx that there seemed to be in some cases a difference between the extinction of a near the space d and that near c , the latter being greater. So far the action might be considered as slightly more intense than usual, whereby the subdivision of the quadrants is plainer. However, the position of the optical normal as given by von Lasaulx demands that the bisectrix should cut the clino axis, i. e., the line of OP in the figure, at an angle of about 5° and the vertical axis at about 56° , while the bisectrix in the present case is inclined 5° to the clino axis and about 46° to the vertical axis, the normal consequently intersecting the latter at about 44° . In all crystals and in each quadrant the bisectrix lies in a dome which is steeper than the basal plane by about 5° , and hence truncates the angle between OP and ∞P , bringing the optical normal to an inclination of about 44° with the vertical axis. The close

agreement in other respects suggests the possibility that the position of the bisectrix relative to the clino axis may have been transposed by von Lasaulx.

The portions lettered *c* in Fig. 2 correspond in position and character to those of Fig. 1. An attempt has been made to indicate their irregular form and their relation to other parts. Usually based upon the outline of $P\infty$, they may spring from any part of the line of ∞P , and universally run toward the centre, often wedging out before reaching it and never penetrating segments *a'* or *b'*. Parts corresponding to *d d* in the Fig. 1 are here represented by a few bars at right angles to OP , but, although most numerous near the sharp line between *a'* and *b'*, they do not appear in sufficient quantity to form a distinct field, as *d* in Fig. 1. These interpositions seem most probably to be portions of *a'* included in *b'* and *vice versa*. The lower part of Fig. 2 shows the irregular relation of *b'* to *a'* in some cases, the dividing line being sharp while very much broken. In *b'*, which is thus enlarged, are numerous interpositions which are most sharply defined and apparently thickest on the side opposite *a'*, while thinning out toward that area. Some bars in *b'* seem to have a thin wing-like appendage on the side next *a'*. The orientation of these interposed bodies cannot be definitely ascertained, but they seem to correspond closely to the adjacent division of the next quadrant.

The areas *c c* often contain stripes corresponding to *a* and *b* and also more rarely of *b'* or *a'*. Fig. 2 shows how each repetition of ∞P is accompanied by portions which are banded parallel to its outline and correspond optically to all other parts of the same position. In some crystals a close examination shows a delicate zonal structure, parallel to that of *a* or *b*, in small irregularly shaped parts of *c*, and as these are almost always thin and underlaid by substance of other orientation, so that a uniform extinction does not take place, it seems quite probable that these portions showing aggregate polarization are made up of an intergrowth of thin flakes of *a* and *b* with the ortho axis in common, but not in fully coincident position otherwise; corresponding thus to the known tendency of the mineral in larger crystals and which is characteristic of those from this locality. Von Lasaulx also suggests this explanation, but thinks the brilliant and strongly contrasted polarization of parts whose extinction angles should so nearly coincide is antagonistic. The interference of light in passing numerous laminæ and possible tension arising from the manner of intergrowth assumed seem, however, sufficient to account for this strong action.

During the study of the twin structure in phillipsite, Trippke^a made a section through the centre of a double twin crystal, parallel to the clinopinacoid of one of the simple twins and obtained thus a form cor-

^a P. Trippke. "Beiträge zur Kenntniss der schlesischen Basalte und ihrer Mineralien." Breslau, 1878. (Dissertation.)

responding to the crystals of stilbite. Fig. 3 is a reproduction from his work showing the optical division of the section. Its formal correspondence with that described for stilbite is noteworthy. The segments *a* and *b* correspond to *a'* and *b'* of Fig. 2, even to the interposed bars at right angles to *OP*, which are interpreted by Trippke as inclusions of *a* substance in *b*, and the reverse (loc. cit., p. 39). The areas *c*, *d'*, *f*, *e'* represent, however, four distinct individuals which do not correspond to *a* and *b* of Fig. 2, except in form. Likewise the wedge-shaped portions *a'* and *b'* do not correspond to *c* of the stilbite, for they represent substance whose basal plane falls parallel to $\infty P\bar{a}$ of *a* and *b*. If the various parts of the stilbite crystals do possess the ortho axis in common, as indicated by the observations of von Lasaulx and by a single section secured parallel to *OP* in a Table Mountain crystal, then the structural correspondence between Figs. 2 and 3 is meaningless except for the segments based upon *OP*. These are actual equivalents.

The material thus far obtained from Table Mountain does not permit of crystallographic measurements of sufficient accuracy to determine definitely whether the division into octants, indicated by the optical behavior, can be traced in the outer form or not. The incomplete results obtained have been given in detail because it seems probable that the material examined by von Lasaulx does exhibit in less distinct form the same action. It is hoped that an attempt to secure better specimens from Golden may be successful, so that further examination may be made.

ANALYSIS.—Pure crystals gave on analysis the following:

	VI.
SiO ₂	54.67
Al ₂ O ₃	10.79
CaO	7.98
Na ₂ O	1.47
H ₂ O	19.16
	100.00
(W. F. Hillebrand.)	

Oxygen ratio:

RO : R₂O₃ : SiO₂ : H₂O

1 : 2.97 : 10.97 : 6.41, instead of

1 : 3.00 : 12.00 : 6.00, as required by the ordinarily accepted formula.

CHABAZITE.

GENERAL.—With the exception of stilbite this is the oldest of the colorless zeolites. In most cases where several zeolites occur together chabazite forms the lining of the cavity and the others are deposited upon it. It is often found alone, however, and excellent specimens are abundant.

The glassy white, or rarely pinkish, crystals have the usual rhombohedral form and the faces are occasionally as much as 1^{mm} in diameter.

The crystals are usually twins of interpenetration. In some of the smaller cavities are subdividing walls of chabazite or miniature columns composed of many small crystals. A second generation of chabazite came after thomsonite and analcite, but the crystals are few and very minute.

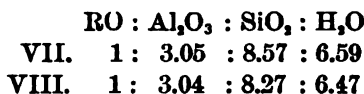
CHEMICAL COMPOSITION.—Chemical analysis of clear crystals gave as follows:

	VII.	VIII.
SiO ₂	47.86	47.18
Al ₂ O ₃	19.30	19.67
Fe ₂ O ₃	*0.12	
CaO.....	9.94	9.74
SrO.....		6.43
K ₂ O.....	0.25	0.37
Na ₂ O.....	0.52	0.51
H ₂ O.....	22.67	22.15
(W. F. Hillebrand.)	100.16	100.05

* From attached limonite.

	Per cent.
Loss on drying over sulphuric acid.....	2.05
Total loss at 100° C.....	4.76
Total loss at about 300° C.....	12.45
Loss above 300° C.....	3.70

From the above analyses it is impossible to deduce a formula strictly in accordance with that of Rammelsberg⁶ or that of Streng.⁷ Assuming part of the alkaline earths to be replaced by alkalies, the following oxygen ratios are obtained:



It is highly probable that a part of the water is basic. The presence of strontia in such quantity is noteworthy.

The material was not examined microscopically.

THOMSONITE.

OCCURRENCE AND GENERAL DESCRIPTION.—This zeolite followed closely upon the chabazite; indeed its earliest aggregates are so intimately associated with that mineral as to make it evident that the deposition of the one had begun before that of the other had ended. The mineral occurs in very minute rectangular blades, which are placed upon each other like the leaves of a closed fan, and the very compact combinations of such aggregates are usually arranged in a more or less distinct radiate manner. Sometimes spherical forms result, in other cases columns, by radiation from an axis, or, less frequently, walls, the blades standing at right angles to the central plane. Where crystals of yellow

⁶ Zeitschrift d. D. geol. Ges., XXXVI, 220, 1884.

⁷ Berichte d. oberhess. Ges., etc., XVI, 74, 1877.

calcite were not covered by chabazite the thomsonite has never failed to coat them, the blades being approximately perpendicular to the crystal faces. When a large surface of chabazite has been completely coated by the more or less radiate aggregates of thomsonite, forming an undulating surface, the whole has a most delicate silken lustre, while that on a fractured surface of a spherical mass is more satin-like. The aggregates are white when pure and single blades are transparent.

It is difficult to obtain isolated leaves, and they are then so thin as to affect polarized light but slightly, still it was definitely determined that the direction of total extinction between crossed nicols is parallel to the longitudinal axis. By examination of the ends of the blades under the microscope with a power of 90 diameters, it could be seen that the vertical edges were formed in many cases by a plane at right angles to the dominant surface. Occasionally a prism was found with angle very near 90° , and in a few cases both forms together were seen. These planes correspond to the macropinacoid (dominant) prism and brachypinacoid of thomsonite, as given by all authorities. The termination seems to be the basal plane. The average thickness of these blades is about 0.01^{mm} . Toward the close of the zeolitic formation a second generation of thomsonite was deposited. The blades are in this case longer than in those of the first while the other dimensions remain about the same. In combination with the base upon the crystals of this latter growth are apparent brachydomes, whose angles with the base were most frequently measured at about 145° or 135° .

The blades of the second generation, when deposited upon those of the first, have the same crystallographic orientation and serve simply as prolongations of the latter. Through the usual slight yellow tinge of the recent growth, the line between the two is clear. The long blades of the second growth of thomsonite often form bundles resembling rough prismatic crystals, and these bundles arranged in a loosely and irregularly radiate manner form bunches an inch or more in diameter upon which the delicate needles of mesolite have a special tendency to deposit themselves.

The thomsonite of Table Mountain was first identified through a quantitative analysis by Carlton H. Hand, at the time a student in the School of Mines at Golden. The analysis was not published and has been lost.

CHEMICAL COMPOSITION.—The following results were obtained by the analysis of different specimens of thomsonite from Table Mountain:

	IX.		X.		XI.		XII.		XIII.
			a	b	a	b	a	b	
SiO ₂	40.88	40.68	40.70	41.21	41.17	42.66	42.25	29.29	41.68
Al ₂ O ₃	29.68	30.12	29.75	29.71	.....	.....	29.25	29.29	.....
CaO	11.88	11.92	11.89	11.84	11.88	10.90	10.90	10.90	.....
Na ₂ O	4.72	4.44	.....	5.62	.....	4.92	.....	.....	.....
H ₂ O	12.91	12.86	.....	12.20	.....	12.28	12.24	.....	.....
(W. F. Hillebrand.)	100.07	100.02	.....	100.08	.....	100.01	.....	.....	.....

Oxygen ratios:

	RO : R ₂ O ₃ : SiO ₂ : H ₂ O			
IX	1	: 3.03	: 4.73	: 2.49
X, mean of <i>a</i> and <i>b</i>	1	: 3.09	: 4.77	: 2.51
XI, mean of <i>a</i> and <i>b</i>	1	: 2.98	: 4.68	: 2.31
XII, mean of <i>a</i> and <i>b</i>	1	: 3.14	: 5.19	: 2.50

DISCUSSION OF ANALYSES.—In all of these analyses the figures under *b* denote repeated determinations. Analysis IX was made upon material taken from the purest and finest specimen of thomsonite as yet obtained. Separation from the underlying thin layer of chabazite was complete. The material for X was also selected with the greatest care from a very pure specimen. Imperfectly spherical aggregates were broken up quite finely, and each particle appropriated for analysis was first closely examined with a strong lens in order to detect any trace of chabazite. Thinking it possible that a small amount of chabazite might have escaped notice, a second portion of thomsonite from the same specimen was procured by breaking off the ends of the blades, and this was found to contain 41.63 per cent. of SiO₂, (XIII). A microscopical examination of this material showed that these blades of thomsonite contained very small, irregularly rounded particles imbedded in the outer surfaces. These particles, which are clear or slightly yellowish, do not affect polarized light perceptibly and are not crystalline in form. They are present in varying quantity toward the termination of nearly all blades, but are usually entirely wanting in the lower portions of all aggregates. In the material yielding IX they were present in less quantity than usual, and even if they consisted of pure silica could have affected the result but slightly.

Analyses XI and XII were made upon substance known to be slightly contaminated by delicate hairs of mesolite which could not be fully removed. Both represent thomsonite from bunches of the kind mentioned above.

RELATION TO "MESOLE."—In the hope of throwing some light upon the cause of the difference between the composition of normal thomsonite (oxygen ratio 1 : 3 : 4 : 2½) and the variety sometimes called "mesole" (oxygen ratio well represented by those of the foregoing analyses), the ratios for all the analyses of mesole given in Dana's System of Mineralogy, and of such others as could be obtained, were calculated and the results examined.

Intermixture of free silica or of mesolite has been generally considered the cause of the excess of silica in mesole. While the presence of either or both of these substances may be a sufficient explanation in some instances, and in two of the above analyses (IX and X) undoubtedly is, to some extent at least, a true one, it will not answer for a majority of the published analyses examined. Only one of these, on

Nova Scotia material, by How, affords a ratio very near that furnished by IX and X above.

While positive proof is wanting of the total absence of free silica in the purest of the Golden thomsonite analyzed, the most thorough microscopical examination failed to reveal its presence or that of any other foreign matter.

Mesolite cannot be the disturbing element here, because in order to raise the silica 3 per cent. above that of normal thomsonite there would be required an admixture of not far from 50 per cent. of mesolite, which amount would also have raised the oxygen value for water. It seems indispensable to a solution of this question that numerous and accurate analyses should be made of this variety of thomsonite from as many localities as possible, and that careful microscopical examination should in every case furnish as far as possible a guarantee of the purity of all material taken for analysis.

ANALCITE.

GENERAL DESCRIPTION.—Analcite follows thomsonite in time of deposition. At the locality mentioned on North Table Mountain its crystals are pure white or transparent and vary in size from very small ones to those nearly an inch in diameter. The predominating form is the common trapezohedron 202 having its octahedral edges evenly truncated by $\frac{1}{2}0$. The appearance of $\frac{1}{2}0$ is very characteristic of the Table Mountain analcite, though the form is never prominent and is usually represented by an exceedingly narrow line. According to Zirkel⁹ the form $\frac{1}{2}0$ has been observed but once on analcite, viz., by Laspeyres on that from the Kerguelen Islands. A second generation of analcite was observed, analogous to that of chabazite, the crystals being very small and clear. They were deposited upon apophyllite.

On the eastern side of North Table Mountain analcite is often present alone, filling small cavities completely and developed in immense crystals in the larger ones, some being nearly 2 inches in diameter. The faces of such large crystals are often uneven through depressions or other irregularities bounded by faces of 202.

On South Table Mountain analcite is more abundant than any other zeolite. Large cavities have a floor of analcite but always in quite small crystals. Natrolite is almost invariably deposited upon it and frequently small cracks are filled with the same mineral associated with calcite or natrolite. Analcite was also found in spaces between the pebbles of a conglomerate bed, not far below the basalt, the pebbles being of basic eruptive rocks.

OPTICAL BEHAVIOR.—The anomalous optical properties of much analcite have been the subject of careful investigation by numerous able mineralogists, some of whom have sought the explanation in a complicated twin structure by which a substance of lower degree of sym-

⁹Naumann-Zirkel, "Elemente der Mineralogie." Leipzig, 1881.

metry may imitate a higher, while others have referred the phenomenon to double refraction arising from inner tension. Since the exhaustive researches of Ben-Saude⁹ few have opposed the latter view, according to which all optical action in analcite, which is abnormal for a mineral crystallizing in the regular system, is regarded as secondary and produced by molecular disturbances due to changes of temperature. The mode of formation of the mineral and the crystal forms developed determine the character of the anomalous action.

In the preliminary description of the Golden zeolites¹⁰ it was stated that the analcite of Table Mountain "is doubly refractive, but so irregularly that it cannot be well used in confirmation of the interesting observations of Ben-Saude." At about the time of this publication a suite of the Golden zeolites was sent to Professor Carl Klein, of Göttingen, the foremost in the group of those who have sought to explain many optical anomalies in crystallized minerals by the theory of inner molecular tension due to secondary causes. The thorough examination of the Table Mountain analcite by Professor Klein, the results of which were published in the *Neues Jahrbuch für Mineralogie*, etc. (1884, I, 250), shows that the above statement is correct only for the larger crystals, while the smaller and most perfect ones agree entirely with the observations and conclusions of Ben-Saude. Renewed examination by us upon minute and carefully-selected crystals fully confirms this testimony.

Professor Klein also subjected our material to investigation in a direction recently followed by him in regard to many minerals with eminent success, particularly in the cases of boracite¹¹ and leucite.¹² By means of an apparatus devised for the purpose the effect of heat upon the optical properties of a given mineral can be observed under the microscope. The application of this method of research to the Table Mountain analcite enables Professor Klein to state that in sections parallel to $\infty 0 \infty$ and $\infty 0$ the doubly refractive action of the various segments into which the crystal is divided becomes less and less, and finally disappears entirely, leaving an isotropic field. By thin sections this change is effected rapidly, while in the thicker ones it is retarded, and in some cases was not wholly successful. These investigations seem to demonstrate clearly that analcite is a regular mineral, whose anomalous optical properties are due to molecular disturbances produced by a decrease in temperature from that prevailing at the time of formation of the mineral.

⁹ "Ueber den Analcim." *Neues Jahrbuch für Mineralogie*, etc., 1882, I, 41.

¹⁰ *Am. Jour. Sci.*, III, XXIII, p. 452, 1862.

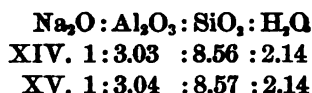
¹¹ *Neues Jahrbuch für Mineralogie*, etc., 1882, I, 235.

¹² *Ibid.*, 1884, II, 49.

CHEMICAL COMPOSITION.—Analyses of crystals, apparently pure, which were, however, not examined microscopically, gave as follows:

	XIV.	XV.
SiO ₂	55.82	55.80
Al ₂ O ₃	22.42	22.45
Na ₂ O	13.48	13.45
H ₂ O	8.88	8.36
(W. F. Hillebrand.)	100.10	100.05

Oxygen ratios:



The excess in silica and water is most probably due to presence of hydrated silica.

APOPHYLLITE.

GENERAL DESCRIPTION.—This mineral occurs in well-developed crystals of prismatic habit with ∞P and P predominating, while OP is in most cases quite subordinate or wanting entirely. The larger crystals which are occasionally half an inch in diameter, are often of a greenish tinge, sometimes quite pronounced, and possess more or less uneven surfaces produced by a repetition of the crystal faces, so that the termination is made up of a large number of small pyramids.

The prismatic surfaces are roughened by depressions or elevations bounded by prism and pyramid planes. This feature is very prominent in all large crystals, while the smaller ones are in contrast sharp and clear with smooth, brilliant faces. Especially noticeable on these small and clear crystals, though not peculiar to them, is a replacement of the pole edge of the pyramid by a small re-entering angle formed by pyramid faces. This angle is nowhere prominent, yet may be easily identified on all clear crystals, both large and small. No corresponding irregularity of any kind could be detected on the dimetric prism of these crystals.

As a rule the largest crystals occur in the small cavities, and their growth has been more or less hemmed by the walls, while the more perfect crystals are present in the large cavities, and are usually small and numerous.

OPTICAL PROPERTIES.—Apophyllite is another of the group of minerals exhibiting in many cases an optical behavior not in accordance with the outward symmetry, and the mineral from Table Mountain shows this anomalous action in typical form. The thorough investigation of such minerals having become within the past few years a work for the specialist, with appliances not at our disposal, we shall confine ourselves to a simple statement of observed facts. We are able, however, to refer to the published results obtained by Professor Klein from an examination of material from Table Mountain. Unfortunately but a

few small crystals of this locality are suitable for such study, owing to the irregularities of form common to the larger ones, so that a satisfactory suite of specimens could not be placed at Professor Klein's disposal. His results are contained in the same article with those upon analcite.¹³

The mere observation of the optical anomalies of apophyllite is no difficult matter, provided good crystals are available, for the easily-obtained sections parallel to the perfect basal cleavage planes are most suitable for the purpose. It is, however, a significant fact that only the most perfect and symmetrically developed crystals exhibit the peculiar action in sufficiently simple form to permit a satisfactory description. With all apparent, and sometimes, it must be confessed, without visible irregularities in form, there appear variations and distortions of the more regular action about to be described.

The Table Mountain apophyllite crystals are bounded by $\infty P \infty$ and P with 0 P as a frequent addition. If a regular crystal of this form be divided into a number of sections parallel to the basal cleavage plane, there will be small ones of square outline, situated in the pyramid near the apex; larger ones of octagonal form through the intersection of both pyramid and prism; and still lower, square ones again from the prism alone. Such sections, ground to the desired thinness and mounted in Canada balsam, show the following peculiarities when examined in parallel polarized light. Unless otherwise stated the examination takes place between crossed nicols, and the position in which the diagonals of the pyramidal section are parallel to the planes of vibration in the nicols is designated as position A, that produced by revolving the crystal section through 45° , as position B.

Figs. 4, 5, and 6, represent the relation in a crystal examined and described by Professor Klein,¹⁴ all of them in position A. Fig. 4 illustrates the appearance in a section near the apex of a crystal having 0 P and showing the small re-entering angles above mentioned. In the centre is a dark field, whose outlines are only approximately parallel to those of the pyramid. The outer zone is then divided in segments based upon the four sides, the opposite pairs having the same optical orientation. Fig. 5 represents the division in the octagonal section cutting $\infty P \infty$ and P. The central field is here much smaller and the segments upon P consequently larger. Based upon $\infty P \infty$ are low triangular spaces of still different optical action. Fig. 6 shows the relations in a section of the same crystal taken in the prism. The central field is here very small, while those areas corresponding to the outlines of $\infty P \infty$ have increased very markedly. The optical behavior of these divisions in position A is usually as follows: The central field is nearly or quite dark, the sectors based on outlines of P are light and equal,

¹³ Neues Jahrbuch für Mineralogie, etc., 1884, I, 253.

¹⁴ These figures taken from the cited article.

while those upon $\infty P \infty$ are not homogeneous in action. The areas based upon P are optically biaxial, the plane of the axes lying normal to the outline of P adjoining. When a gypsum plate producing red light of higher order is inserted, and so situated that the lesser axis of elasticity runs from the upper left-hand to the lower right-hand quadrant, the blank sectors appear yellow, the dotted ones blue, while the inner field has more or less perfectly the red color of the outer field of vision. The sectors based upon $\infty P \infty$ are usually variegated in color, red, blue, or yellow, as will be described further on. In position B the whole becomes dark except the irregular sectors adjacent to $\infty P \infty$.

The statements of Professor Klein are chiefly directed to show that the optical properties observed are, to a very large degree, dependent upon the crystal faces developed. Thus the crystal whose sections are figured had a well-developed basal plane, to which fact is attributed the presence of the central field, while the decrease in size, as the sections are taken deeper in the crystal, corresponds to the distance from $O P$. He states that in a crystal without a basal plane the central field is wanting. The appearance of the prism $\infty P \infty$ as a boundary of a section is accompanied by the appearance of the low triangular spaces of irregular optical behavior. The biaxial fields seem definitely related to the outlines of P .

The examination of several crystals with reference to this relationship between outer form and optical action has shown us that any generalization with regard to $O P$ and the central field is impracticable. In several crystals showing no base at all the dark central field is present, in one case being large near the apex and very small in the prism; in another case the reverse; also in crystals with $O P$ developed this field is sometimes smallest near that plane, and again it does not vary materially in size from the pyramid to the prism. In no case, however, has the prism $\infty P \infty$ appeared as a boundary of a section, without an adjacent field in which the action is often complex, the complexity increasing as the section is taken lower in the crystal. No sector in this position has ever been seen independent of the development of $\infty P \infty$.

The figures of Professor Klein are intended to illustrate the most regular action observed, and it is quite natural to assume that this simple relation of optically different parts is largely dependent upon the regularity in the development of the crystal form. The deviations from this simple relation and action of individual parts have never been fully described, but in the series of sections we have examined these variations are very numerous and seem quite as important in considering the cause of the optical phenomena as the more regular condition occasionally seen.

The central core is very variable in form. Within a given crystal it often changes perceptibly from section to section either in size or in outline. As has been stated, it may be largest near the apex of the

crystal (whether $0 P$ is developed or not) and steadily decrease in size downwards, or its apex may be in that of the pyramid, and in some cases it runs as an inner prism through the whole observed part of the crystal. Its section is but rarely square, although rectangular in many cases, and this variation has no observable relation with the prominence of adjacent pyramid faces. The more perfectly rectangular its outline the sharper its boundaries are, and the more homogeneous its optical action. Variations from the rectangle are produced by broken side-lines, by the deviation of its angles from 90° , and by an increase in size until it can no longer be inscribed within the prism $\infty P \infty$. With all such irregularities are combined disturbances in the optical action of the centre. In the simpler instances, by position A the field is not wholly dark and several faint black crosses are seen whose arms are parallel to the diagonals of the pyramid, and revolve with the section, disappearing more or less completely in position B. These arms rarely cross each other at exactly 90° , and especially where the side lines of the rectangle are broken the field is divided into numerous irregular areas, each having by position A a black cross whose arms may join at any angle. These revolve with the section and either disappear or become less distinct by position B. In one section the optical division is quite regular, in that by position A the field is composed of a mosaic of light and dark squares or rectangular blocks, whose sides are parallel to the outlines of the prism $\infty P \infty$. In position B the same structure is visible with the dark squares as the light ones. The lighter areas are very faint and shade off into the darker ones. With the insertion of the gypsum plate the place of the black cross is sometimes indicated by bushy indistinct blue and yellow arms, normal respectively to the adjacent blue and yellow segments on the outlines of P . In two or three cases one side of the central field is absent, and there is a gradual shading from the adjoining sector into the area of the centre. The opposite side of the field is very sharp and clear in such instances. By using the gypsum plate the change is very distinct, from the normal red next to the sharp outline, by transition shades out to the distinct yellow or blue of the sector.

The segments based upon P are much less subject to variation than the central field. They are always present and usually prominent. Normally they appear equally light in position A, but opposite pairs differ in intensity upon a slight revolution, and are wholly dark in position B. On insertion of the gypsum plate, in position A, one pair appears blue, the other orange-yellow. In regular crystals the dark lines which separate them run from the angles of the pyramid, or normal to $\infty P \infty$ if its faces are developed, to the angles of the central field, as in Figs. 4, 5, and 6. If the inner field is not regular, these lines must bend to meet the angles, and in fact they are often wholly irregular curved or broken lines, neither normal to each other nor to the outline of $\infty P \infty$. An optical variation of these segments is frequent, in that the outer

portions or a broad band through the centre, parallel to the outline of P, is much lighter than that portion near the central field. If the gypsum plate is inserted the color of the lighter parts is purer blue or yellow, and shades off into reddish hues toward the red centre. In position A indistinct dark figures are sometimes seen, and these usually spring from a point on the surface or from the angles of the central field. Fissures when present commonly furnish a number of centres for such disturbances.

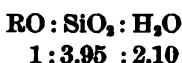
Finally, the areas based upon $\infty P \infty$ are quite variable both in form and behavior. They are sometimes very low, perfect triangles, and in such cases their action is often simple. In position A they are dark, in B light. With the gypsum plate inserted they are red in position A, while in B opposite pairs are respectively blue or yellow, as with the pyramidal segments in the former position. When complex they consist chiefly of laminæ parallel to $\infty P \infty$. In position B, with gypsum plate, a part of these laminæ appear red, the remainder blue or yellow.

The simple recital of the optical variations observed seems sufficient to deter any one from an attempt to explain the anomalous action of apophyllite on a theory of complex twinning. The insensible gradations and shadings between all structures and optical conditions seen, are much more characteristic of the phenomena due to unequal tension or pressure in glass and colloidal substances, than of any complex twinning definitely known in a mineral.

CHEMICAL COMPOSITION.—In chemical composition this apophyllite is quite normal, the fresh substance yielding the following:

XVI.	
SiO ₂	51.89
Al ₂ O ₃	1.54
Fe ₂ O ₃	0.18
CaO	24.51
K ₂ O	2.81
Na ₂ O	0.89
H ₂ O	16.53
F	1.70
	100.00
O for F	0.73
	99.97
(W. F. Hillebrand.)	

Considering all potassium and sodium as combined with fluorine, the following oxygen ratio is afforded:



The theoretical ratio 1:4:2 would be still nearer approached were it not for a probable slight loss of silica and excess of water, scarcely to be avoided in analyses of silicates containing fluorine. The Fe₂O₃ is undoubtedly owing to minute particles of limonite which could not be completely removed. The Al₂O₃ is much higher than in most

analyses, and the condition in which it is present seems undeterminable.

ALTERATION.—The Table Mountain apophyllite is frequently subject to alteration in a peculiar manner, which is, so far as we can ascertain, different from anything previously observed for that mineral. By this alteration a pearly-white, very finely-foliate substance is produced in the basal cleavage fissures of the apophyllite. The decomposition begins at the surface and progresses inward, the flakes of the newly-formed substance lying parallel to the cleavage planes. Some crystals which are outwardly snowy white, show perfectly fresh substance within. When the outer surface of an altered crystal is dull the resemblance to albine is marked, but on fracturing such a crystal the distinct foliation and lustre show the different nature of this substance.

As more or less apophyllite is usually mixed with the alteration product it was quite difficult to ascertain its chemical composition. Material apparently very pure was finally obtained from the specimen in which the decomposition was most advanced, by treatment in the following manner: The finely-powdered substance was stirred up in water, and the finer portions were poured off from the heavier impurities; the material suspended in the water was allowed to settle, the clear liquid was decanted, and the residue evaporated, accidentally *quite* to dryness. It having been found that the air-dried material lost several per cent. of water over sulphuric acid, it was certain that some loss had been occasioned by drying on the bath; hence the drying was completed at 100° C., and the following analysis was then made:

XVII.	
SiO ₂	67.96
Al ₂ O ₃	8.48
Fe ₂ O ₃	1.04
CaO	5.47
MgO	0.58
K ₂ O	1.23
Na ₂ O*	0.74
H ₂ O	14.55
F	none
(W. F. Hillebrand.)	100.00

* By difference.

The Fe₂O₃ comes from certain reddish flakes which could not be separated. The H₂O is, from reasons above given, much too low, and the other figures are consequently too high.

Neglecting Fe₂O₃ and H₂O the following oxygen ratio is obtained:

$$\begin{aligned} \text{RO} : \text{Al}_2\text{O}_3 : \text{SiO}_2 \\ 1 : 1.86 : 16.66 \end{aligned}$$

from which no satisfactory formula is deducible.

It is plain that this alteration product has nothing in common with albine except the color, Knop¹⁵ having proved, for many cases at least, that the latter substance is chiefly calcite.

MESOLITE.

GENERAL DESCRIPTION.—Mesolite is the last of the minerals deposited at the locality on North Table Mountain where all of the species thus far described occur so often together that their order of succession is plain. The mineral appears uniformly in masses composed of exceedingly delicate needles loosely grouped together, very much like the spicules of a fine sponge. Such light aggregates frequently fill the smaller cavities entirely. In the larger ones the bases of the rounded bunches, 1 to 2 inches in diameter, often touch each other. The very latest deposition, the finishing touch so to speak, is a thin film coating the whole mass. This is sometimes a continuous membrane, and in other cases more like a thick cobweb. The exquisite delicacy of some of these films is quite wonderful. In rare cases bunches on the upper and lower walls of a cavity are united by such a membrane. Single needles are clear, but the aggregate appears pure white.

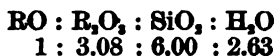
As was mentioned under thomsonite, the loose aggregates of the second generation of that mineral seem specially suited to attract the deposition of mesolite.

None of the mesolite needles are large enough to allow any determination of their crystal form, even under the microscope at a high power. They seem simply like very fine transparent hairs.

CHEMICAL COMPOSITION.—The identification as mesolite rests upon the following chemical analysis:

	XVIII			Mean.
	a.	b.	c.	
SiO ₂	46.14	46.02	46.33	46.17
Al ₂ O ₃	26.88	26.87	.....	26.88
CaO.....	8.77	.....	.....	8.77
Na ₂ O.....	6.19	.....	.....	6.19
H ₂ O.....	12.17	12.17	12.13	12.16
(W. F. Hillebrand.)	100.15	.....	.....	100.17

Oxygen ratio :



If mesolite be considered as a mixture of the isomorphous silicates contained in scolecite ($\text{CaAl}_2\text{Si}_2\text{O}_{10} + 3 \text{ aq}$) and natrolite ($\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_{10} + 2 \text{ aq}$), the present occurrence would answer very nearly to the requirements of the combination of 2 of scolecite + 1 of natrolite, the percentage of which would be: SiO₂ 46.32, Al₂O₃ 26.40, CaO 9.61, Na₂O 5.32, H₂O 12.35=100.00.

¹⁵ In Blum, Die Pseudomorphosen, etc.; Dritter Nachtrag, 1863, p. 41.

NATROLITE.

DESCRIPTION AND ANALYSIS.—Natrolite occurs much less abundantly than any of the species thus far described, and seems to be restricted locally to the northern part of South Table Mountain. It usually appears in delicate prisms sparingly deposited upon analcite or associated with that mineral in fissures. It has also been observed upon yellow calcite, chabazite, and thomsonite.

The crystals show only ∞ P and P; they extinguish light exactly parallel to the prism, and are therefore of the normal rhombic type. The microscope shows many crystals to be partially coated with calcite, which explains the presence of CaCO₃ in the following analysis of the needles:

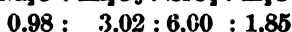
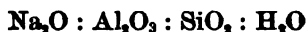
	XIX.
SiO ₂	48.66
Al ₂ O ₃	24.89
CaO.....	4.87
Na ₂ O.....	14.66
H ₂ O.....	* 8.00
CO ₂	† 3.88
(W. F. Hillebrand.)	100.00

* By difference.

† Calculated for total CaO.

There being much less than half a gram of material at disposal for analysis, no attempt at a direct water determination was made. On treating with acid there was a strong effervescence of CO₂; therefore in calculating the following oxygen ratio the CaO was assumed to be present entirely as CaCO₃.

Oxygen ratio:



A study of the ratio thus obtained, however, renders it probable that a small part of the CaO was combined with silica, in which case the CO₂ would be less and the H₂O consequently higher, bringing the ratio still nearer to the theoretical 1 : 3 : 6 : 2.

SCOLECITE.

DESCRIPTION AND ANALYSIS.—Scolecite occurs sparingly in a zone just above that containing a great number of the zeolites. It appears in small spheres or segments of spheres with a radiate structure, and greatly resembles thomsonite, though easily distinguished by the brilliant white color and satin-like lustre. Toward the centre of the aggregates there is often a greenish color.

The mineral only occurs in very small cavities, which are often entirely filled by it and seldom contain any other zeolite. Minute tablets of brown mica which are coated, as are the walls of the cavity, by a lavender-colored material, usually appear as the only associates of the scolecite. It occurs also in some cases with the next species to be described. Chabazite and thomsonite may occur in larger cavities directly

adjacent to smaller ones containing scolecite, but they have never been found with the latter.

The mineral gelatinizes on treatment with hydrochloric acid and was found to have the following composition :

	XX.
SiO ₂	44.08
Al ₂ O ₃	25.24
Fe ₂ O ₃	0.27
CaO	12.77
Na ₂ O	1.04
K ₂ O	0.18
H ₂ O	*14.48
(W. F. Hillebrand.)	100.00

* Difference.

No attempt at a direct water determination was made, owing to the small amount of pure material available.

Oxygen ratio:



$$1 : 3.02 : 6.23 : 3.26$$

It was impossible to free the mineral entirely from attached limonite and an insoluble silicate, which probably accounts for the high values for SiO₂ and H₂O in the oxygen ratio. The agreement with the theoretical ratio 1 : 3 : 6 : 3, is, in any case, close enough to establish the identity of the mineral as scolecite.

LEVYNITE.

GENERAL DESCRIPTION.—To the species levynite is referred a mineral occurring very sparingly in small cavities side by side with those containing scolecite, although the two have never been observed together. When but partially filling the cavity, white or colorless tabular crystals are developed, which resemble very closely the form usually given as characteristic of levynite. Referring to the figures of Dana or Naumann-Zirkel, and adopting the ground form of the latter, the Table Mountain crystals are formed of twins of interpenetration producing hexagonal tablets with 0 R and R as the chief faces, the re-entering angle formed by $-\frac{1}{2}$ R being seldom distinct. R is always striated, often coarsely, parallel to the combination edge with $-\frac{1}{2}$ R.

The faces of R and 0 R are not smooth enough to allow of good reflections, hence the following measurements are not very exact, although sufficiently so to prove the identity in crystal form with levynite:

	Measured.*	Theoretical.
R $\wedge$ R (hor.)	125° 10'	125° 14'
OR $\wedge$ R	117° 32'	117° 22'
R $\wedge$ $-\frac{1}{2}$ R	130° 22'	129° 45'

* Average.

The crystals are attached by an edge, about half of the full crystal being developed free. They are extremely brittle, and fracture very easily at right angles to the horizontal edge of B, i. e., parallel to $\infty P 2$, so that material suitable for optical observation could not be obtained.

Associated with the levynite in some cavities or appearing independently in adjoining ones, is a fibrous mineral, dull white in color and never showing crystal faces. As seen below it is practically identical with the levynite in composition, although so different in formal development. It cannot be referred to any definite species from present data.

CHEMICAL COMPOSITION.—Analysis of the pure crystals of levynite gave XXI, while the allied substance has the composition XXII:

	XXI.	XXII.
SiO ₂	46.76	46.97
Al ₂ O ₃	21.91	22.39
CaO	11.12	10.85
K ₂ O	0.21	1.17
Na ₂ O	1.34	0.79
H ₂ O	18.65	18.08
	99.99	100.20
(W. F. Hillebrand.)		

Oxygen ratios:



XXI. 1 : 2.90 : 7.01 : 4.66

XXII. 1 : 3.01 : 7.15 : 4.58

The water lost in drying has been included in the oxygen ratios, for the reasons given under laumontite. The ratios for dried material are:

XXI. 1 : 2.90 : 7.01 : 4.03

XXII. 1 : 3.01 : 7.15 : 3.94

OTHER MINERALS.

BOLE.

DESCRIPTION AND ANALYSIS.—In many irregular cavities in the scoriaceous crust of the lower sheet, and especially noticeable at about the centre of the northern face of South Table Mountain, is a dark brown clay which probably comes under the above head. It is very dense and apparently homogeneous, and has the peculiar fracture characteristic of such masses. Placed in water it falls apart without decrepitation. It is often associated intimately with a brown massive calcite, and in other cases it alone fills cavities completely. Two specimens, one of a light (XXIV), the other of a dark brown color (XXIII), were subjected to analysis.

	XXIII.	XXIV.
SiO ₂	42.63	46.17
Al ₂ O ₃	18.76	22.08
Fe ₂ O ₃	11.88	4.64
CaO	2.59	2.80
MgO	3.89	2.42
K ₂ O	0.35	} +2.06
Na ₂ O	0.24	
H ₂ O	20.21	20.38
(W. F. Hillebrand.)	100.05	100.00

* By difference.

From these results no satisfactory ratio or formula can be deduced. They probably represent mixtures of different hydrous silicates.

CALCITE.

OCCURRENCE AND DESCRIPTION.—The carbonate of calcium has had three periods of deposition in the basaltic cavities of Table Mountain, two as calcite and one as aragonite. In the form of wine-yellow crystals it preceded even chabazite, being in all observed cases deposited directly on the basalt and coated usually by chabazite or thomsonite. It is rarely found in those cavities to which water has had access through fissures, having been dissolved. The second deposit of calcite came after apophyllite. These crystals are colorless or slightly straw-yellow, and the form of both varieties is commonly that of a sharp scalenohedron terminated by a low rhombohedron.

The aragonite is present only as a snow-white incrustation, apparently with a special tendency to deposition upon chabazite, though often noticed upon apophyllite and thomsonite. It was next to the last mineral deposited, only mesolite having been observed upon it.

The brown calcite mentioned as associated with bole is never present in the zeolitic cavities.

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II.—MINERALS FROM THE NEIGHBORHOOD OF PIKE'S PEAK.

By WHITMAN CROSS and W. F. HILLEBRAND.

GENERAL.

The name of Pike's Peak has become well known the world over in connection with the large and perfect crystals of Amazon stone (microcline) which have found their way into almost every mineral collection of importance, and yet the stranger who ascends the mountain from Manitou may see no sign of that or of any other of the numerous species accredited in a general way to the region. It may be well, therefore, to preface this description with a few remarks concerning the mode of occurrence and the distribution of the Pike's Peak minerals.

The mountain proper rises to a height of 14,147 feet, and is surrounded by many lesser peaks which reach 10,000 feet. The same coarse reddish granite which forms the greater part of all these points extends in a northerly direction for at least 35 miles. Owing to a lack of gold and silver bearing ores the granitic formation has not been thoroughly explored, the region is uninhabited, excepting on certain routes of travel, and the great majority of the mountains and streams are unnamed. Hence it is that minerals found in many remote spots are afterwards labelled simply as from Pike's Peak. For many of the species the inaccuracy is unimportant, as throughout the entire granitic area some of them are surely to be found upon search.

LIST OF SPECIES KNOWN.—Up to the year 1882 the following minerals had been identified with certainty, viz.: Microcline, albite, biotite, muscovite, quartz (smoky and clear), fluorite, columbite, gôthite, hematite and limonite (pseudomorph after siderite), arfvedsonite, astrophyllite, zircon, bastnäsité, and tysonite. The species described in this article have been identified by us since that time, viz: topaz, phenacite, kaolinite, cryolite, pachnolite, thomsenolite, gearsutite, ralstonite (?), prosopite, and elpasolite.

Another series of minerals now in the course of investigation embraces several salts of cerium, yttrium, etc., belonging to species not as yet fully determined, although xenotime and yttrotantalite are probably present. Cassiterite also occurs in small quantity. (See p. 74.)

MODE OF OCCURRENCE.—The reddish granite of the region belongs to a type common in the Colorado range of the Rocky Mountains, and is supposed to be a part of the Archæan formation. It consists of a largely predominant reddish feldspar, to which are added brilliant black biotite and quartz, the latter subordinate, and occurring in small grains. The feldspar consists largely of an intergrowth of orthoclase and albite, somewhat after the manner of perthite.

Throughout the granite body, though much more abundant in some places than in others, are drusy cavities or "pockets" of very variable size, and often distorted by movements of the rock mass. Lining these druses, or entirely filling them in some cases, are crystals of feldspar and smoky quartz, in the first degree, with fluorite, topaz, phenacite, zircon, göthite, hematite, and limonite, as more or less constant companions.

The granite disintegrates rapidly through the action of the weather into a coarse, gravel-like mass, and many of the mountain slopes are covered by such material, with solid rock appearing here and there. On finding fragments of crystal in the *débris* the prospector for minerals, with pick and shovel in hand, endeavors to find the original cavity from which the fragments came. One of these druses has been known to yield more than a ton of crystallized specimens of Amazon stone, smoky quartz, etc.

Vein-like masses, composed chiefly of white quartz and reddish microcline, are also locally abundant, and in these are sometimes found small masses of cryolite and its alteration products, with zircon, astrophyllite, and columbite as observed associates.

CRYOLITE.

LOCALITY.—The point at which cryolite and its alteration products have been found is at the northeastern base of Saint Peter's Dome, a minor peak due west of Cheyenne Mountain and near the toll-road from Colorado Springs to the Seven Lakes, at the southern base of Pike's Peak. The spot lies nearly on the southeastern border of the extensive region within which Amazon stone and its associates occur, and may be thus considered within the "Pike's Peak region," although several miles distant from the mountain proper. The fluorides were first shown in a prospect shaft and in a neighboring tunnel, but visits made to the locality since the first publication have proven the presence of cryolite masses in several of the small irregular veins north and west of Saint Peter's Dome.

OCCURRENCE AND ASSOCIATION.—The manner of occurrence and the relationship of the fluoride masses can now be stated much more clearly than was possible in our first notice. Cryolite, in the massive form to be described, was deposited in the veins of secretion which are

so abundant in the granite country rock, in small but pure and homogeneous masses. Some of these veins have certainly had two periods of secretion, as is shown in the Eureka tunnel, Saint Peter's Dome. This tunnel penetrates for about 200 feet an irregular mass, consisting largely of white quartz and reddish microcline. The greater part of the quartz is the common white vein material containing no included minerals, but a portion of it, appearing in sharply defined angular blocks, is full of the transparent zircon to be hereafter described. Small particles of microcline are also disseminated through this quartz, while in the body of the vein it presents huge individuals, sometimes several feet in diameter. An examination of the tunnel walls shows here and there faces of pure massive fluorides 5 or 6 feet across and sharply defined against both pure and zircon-bearing quartz, the spaces filled being very irregular and angular. No contemporaneous minerals of importance accompany the zircon and cryolite in this vein.

The purity or homogeneity of the white quartz, zircon-bearing quartz, and fluoride masses, together with their irregular forms, seems to indicate different periods of development, and it seems further probable that a time of disturbance, in which the original quartz and feldspar vein was much fractured, produced the irregular spaces subsequently filled by different deposition. The cryolite may have been formed here during the time in which fluorite and topaz were deposited in the cavities of the region to the northwest.

The only mineral observed to be undoubtedly contemporaneous with the cryolite is columbite, which has been seen in small crystals embedded directly in fresh cryolite. At one place astrophyllite blades penetrate cryolite, but these are implanted directly upon the granite wall, and are probably an earlier formation, as are the zircon crystals at their base, and impregnating the granite itself. In the immediate neighborhood arfvedsonite and astrophyllite are quite abundant, both occurring most frequently embedded in white massive quartz. The original locality of tysonite and bastnäsite is not far from Saint Peter's Dome, but little is known to us concerning the manner of occurrence of these minerals.

PURELY SCIENTIFIC VALUE OF THE DISCOVERY.—As numerous inquiries concerning the probable commercial value of this new cryolite locality have been received since the published description, it may be well to emphasize the conclusion which is clearly suggested by the description of the occurrence of the mineral. All the cryolite as yet known occurs in the form of subordinate masses in the veins of secretion which appear here and there throughout the granitic formation, and there is no reason to suppose that masses of economic importance can occur in the region.

RECENT LITERATURE OF CRYOLITE AND ITS ALTERATION PRODUCTS.—The minerals of this group, of which so little was known a few years ago, are now among the best known. As most of the recent pub-

lications are of direct interest to us in describing the material of the new find, a brief mention of the leading articles is in place.

The earliest contribution to be mentioned is that of Prof. P. Groth, then in Strassburg, who instituted a careful investigation of cryolite and its alteration products, several of which had received names without satisfactory proof of their homogeneity, while more or less doubt was justifiable in regard to the chemical composition of all of them. Similar rare minerals of other occurrence were also studied. The purely mineralogical part of this investigation was conducted by Professor Groth personally, while material selected by him was subjected to chemical analysis by Dr. J. Brandl, in Munich. To the papers by Messrs. Groth¹⁶ and Brandl¹⁷ we shall refer frequently in the course of the following description. Owing to better material we are able to supplement in some particulars the results of these gentlemen, and in but a single case, namely, in regard to the composition of pachnolite, is there any discrepancy between our conclusions and theirs.

Concerning the crystallography of the group, Krenner¹⁸ and Des Cloizeaux¹⁹ have made important contributions while the laws of twinning in massive cryolite have been investigated by Mügge.²⁰

GENERAL DESCRIPTION—The pure cryolite appears in massive aggregates of large individuals, quite like that from Greenland. The three prominent cleavage surfaces are often continuous for two or three inches, indicating the size of the individuals present. A delicate pink or even decidedly rosy hue is characteristic of the freshest substance found, but the greater part is either of a faint greenish tinge or dull white, and none so far obtained has the snowy whiteness or the clearness of the Greenland mineral. The color disappears on heating, leaving the cryolite pure white.

The three marked cleavage directions are situated nearly at right angles to each other and one seems slightly more perfect than the other. A parting parallel to these planes is by no means so easily effected as one would expect from the distinctness with which they are seen, a fact explained by the complicated polysynthetic structure to be described.

TWIN STRUCTURE.—As no crystals of cryolite have been found in this locality, the study of the complicated twin structure exhibited by the massive material is no easy matter. The recent investigations of

¹⁶ P. Groth. "Beiträge zur Kenntniss der natürlichen Fluorverbindungen," Zeitschrift für Krystallographie, VII, pp. 375-388 and 457-493, 1883.

¹⁷ J. Brandl. Sitzungsbericht der königl.-bayr. Akademie der Wissenschaften zu München, 1882, p. 118, and Annalen der Chemie, CCXIII, p. 1.

¹⁸ J. A. Krenner. "Die grönländischen Minerale der Kryolith Gruppe." Budapest, 1883.

¹⁹ A. Des Cloizeaux. "Nouvelles observations sur le type cristallin auquel doit être rapportée la cryolite." Bull. Soc. Min. d. Fr., 1883.

²⁰ O. Mügge. "Über die Zwillingbildung des Kryolith." Jahrbuch d. wiss. Anstalten zu Hamburg, 1883, p. 57.

Krenner, and especially those of Mügge upon the massive mineral from Greenland, have, however, done much to make the relations clear.

Dana²¹ mentions ∞ P, Websky²² 0 P and ∞ P ∞ , and Krenner²³ ∞ P and $\frac{1}{2}$ P as twinning planes identified upon crystals of cryolite. Mügge²⁴ seems to have identified $\pm \frac{1}{2}$ P as a twinning plane in the massive material, independently of Krenner's determination. In all the above-mentioned laws the axis of revolution is the normal to the twinning plane, which is usually the composition face. The polysynthetic development of various laws was briefly alluded to in the first notice of the Colorado cryolite, and the descriptions of Mügge show that a similar, although by no means equally complicated, structure exists in the Greenland mineral.

The well known pseudo-symmetry of cryolite is illustrated by the following values, taken from Krenner: $\beta = 89^\circ 49'$; the prism angles are $88^\circ 2'$ and $91^\circ 58'$, the angles between 0 P and opposite prism faces are $90^\circ 8'$ and $89^\circ 52'$. The axes of elasticity are also situated in peculiar agreement with this symmetry, the bisectrix lying in the clinodiagonal section, inclined $43^\circ 54'$ to the vertical axis and $45^\circ 55'$ to the clino axis. It is to be noticed that by all the above-mentioned laws of twinning the planes of 0 P and ∞ P are brought in so nearly coincident positions that the deviations are unnoticeable upon the cleavage surfaces of the massive substance.

The examinations of Mügge were conducted upon thin sections lying in water, the index of refraction of the liquid being almost equal to that of cryolite. Our observations were made upon sections prepared in the usual manner. As none of them exhibit anything corresponding to the results obtained by Mügge on heating to a temperature of over 400° C., it is assumed that no change in the optical properties was produced by the temperature necessary in mounting these sections in balsam.

Although we cannot in the cleavage material distinguish with certainty between ∞ P and 0 P, or between the positive and negative quadrants, still, if from a given cube, sections be prepared parallel to each of the three cleavage faces, we should be able to observe the relations of all twinning laws seen to each other and to a ground form which can be assumed. For a clear distinction of all the individual parts it is necessary to examine the thin sections between crossed nicols and with an inserted gypsum plate giving the field of vision a red color of the higher order. As nearly all the twinned parts are symmetrically related to ∞ P or 0 P, the first position in which their relations can be seen to advantage is secured by placing the cleavage lines in each section $\pm$ to the principal sections of the crossed nicols. This position is hereafter designated as position I. It is evident that the extinction in the basal section takes place parallel to the diagonals of the prism, as indicated

²¹ System of Mineralogy, 5th ed., p. 127.

²² Neues Jahrbuch für Mineralogie, etc., 1867, p. 810.

²³ *Loc. cit.*

²⁴ *Loc. cit.*

by the cleavage lines, i. e., about 45° from each. The theoretical extinction parallel to a face of ∞P is $31^\circ 15'$ from the vertical axis (Groth), which direction lies parallel to one set of cleavage lines.

The various laws of twinning observed will now be taken up and the resulting structure parallel to each of the cleavage faces described.

Law a.—Twinning plane and composition face ∞P , axis the normal upon it.

One of the three sections shows a fine banded structure parallel to one set of cleavage lines; this resembles plagioclase twinned according to the albite law, but the boundaries are less clearly defined. In position I alternate bands are blue, the remainder yellow; reversed colors are produced by a revolution of 90° ; extinction occurs at about 31° from the twinning plane, right or left according to color. The second section shows no such banded structure, but extinction takes place at 31° from either cleavage system. The third section exhibits a banded structure with blue and yellow colors, but with nearly coincident extinction at 45° from the twinning line, which is parallel to one cleavage direction.

As experience shows this twinning to be always parallel to one pair of prism faces and there is evidently a definite relation between the other laws and the present, we will assume the left-hand front prism-face as the twinning plane, $\infty P (l)$. The first section was therefore parallel to $\infty P (r)$, the second to $\infty P (l)$, and the third to $0 P$. This assumption is made in all subsequent discussion, so that the relations of the different laws may be correctly expressed.

The laminae are sometimes broad, but more frequently narrow, measuring 0.01 to 0.10^{mm} in thickness. It is therefore difficult to prepare a section so nearly parallel to $\infty P (l)$ that it shall not cut obliquely several of the laminae, producing a broad irregular banding, as represented in Fig. 7. The four vertical bands with irregular boundaries are alternately blue or yellow in position I, and extinguish at 31° right or left.

Law b.—Twinning plane and composition face $\frac{1}{2} P (r)$, axis the normal upon it.

Sections parallel to $\infty P (r)$ usually show in each lamina produced by the first law a structure illustrated by the lower left-hand portion of Fig. 8. The parts of new orientation are represented by the small rectangular or graphic forms lying parallel to the diagonals of the square, right or left as the case may be, and however zigzag the shape the bounding lines are almost always parallel to the diagonals mentioned. These forms are apparently identical with those described by Mügge as twinned parallel to $\pm \frac{1}{2} P$, and they appear in the other two sections in a manner agreeing with this supposition. In Fig. 7 they are represented by the smaller horizontal lamellae which do not cross the boundaries of the broad bands, and in Fig. 9 by the vertical lamellae included in the larger ones. They are therefore cut by the plane $\infty P (r)$ nearly or

quite at right angles, and their inclination is that of the plane $\pm \frac{1}{2} P$, according to which they are intergrown.

The explanation above given is, however, insufficient, as there are particles of three distinct optical orientations among these formally indistinguishable portions. If a lamina cut parallel to $\infty P (r)$ be placed in position I, and then shows a blue color, the visible included parts of the form in question will appear yellow. On revolving the lamina 31° to its position of extinction, it is found that some of those diagonally-situated particles have the same extinction as the lamina containing them, while the others become still brighter yellow and are found to extinguish simultaneously with the adjacent yellow lamina. On moving the section out of position I diagonal parts of the third orientation appear. These were blue in position I, but do not extinguish with the substance surrounding them; on the contrary, they correspond in this particular with the neighboring yellow lamina. It is impossible to definitely determine the laws according to which the substances are twinned, but in Fig. 10 the observed relations are explained in one way. The larger arrows indicate the normal directions of extinction parallel to $\infty P (r)$, with reference to the vertical axis. The area x represents the position of the corresponding directions of extinction in a lamella twinned parallel to the upper right-hand face of the positive hemipyramid, $\frac{1}{2} P (r)$. This will extinguish at 31° to the right from the vertical axis, while corresponding very nearly in color with the inclosing substance in position I. This is considered the equivalent of the law identified by Krenner. The lamella y is related to x as if twinned according to law α , and thus will exhibit parallel extinction with the inclosing substance but the opposite color in position I. The part z corresponds in color and extinction to the adjacent lamina, twinned after law α , and intergrown parallel to $\frac{1}{2} P (r)$ or $-\frac{1}{2} P (l)$.

Careful study of a number of sections has failed to show any method of distinguishing between these various parts aside from their optical orientation. Now one, now another, seems to predominate, and often all three are to be seen in a single lamina.

The sections parallel to $\infty P (l)$ and $0 P$ cut these thin particles at an oblique angle, and their proper optical action is thus so obscured that they cannot be used to test the accuracy of the relation represented by Fig. 10.

Law c.—Twinning plane $\infty P \propto$, axis the normal upon it, composition face ∞P , or an irregular surface near it.

Sections parallel to $0 P$ never show a twinning plane running parallel to either pinacoid, and yet substance is found whose orientation corresponds to the requirements of the above law. This is shown upon $0 P$ by polysynthetic twin structure parallel to the second prism plane, $\infty P (r)$, the laminae extinguishing at 45° and hence presenting $0 P$. (See Fig. 9.) This might be considered as twinning after the prism plane $\infty P (r)$ except that a corresponding structure upon $\infty P (l)$ does

not appear. There is, it is true, a vertical lamellar twinning sometimes seen, but accompanied by the substances intergrown as described under law *b*. This is represented in Fig. 7, and is the natural result of law *c*, which brings $\infty P (r)$ with its twinning after laws *a* and *b* into parallel position with $\infty P (l)$, produces a crossing of the laminae upon $0 P$, and, lastly, brings $\infty P (l)$ parallel to $\infty P (r)$. This latter position is naturally seldom seen in sections, as the part thus twinned is usually a rather thin plate parallel to $\infty P (r)$, of the chief individual. In one case, however, a section parallel to $\infty P (r)$ which exhibits the usual complicated structure over the greater part, passes by an irregular indistinct line into substance of more simple action, like that represented for $\infty P (l)$ in Fig. 7, as if the slightly oblique section plane had cut into the plate twinned after this law *c*. Websky describes the composition face, in the case noticed by him, as irregular, although lying approximately parallel to $\infty P \infty$.

Law *d*.—Twinning plane $\frac{1}{2} P (l)$, axis the normal upon it, composition face $\infty P (l)$, or an irregular surface near it.

By this law $\infty P (r)$ and $0 P$ are interchanged. It seems required to explain the appearance in the section parallel to $\infty P (r)$ of laminae parallel to those of *a*, but with extinction of 45° (see Fig. 8), and the similar laminae on $0 P$ with extinction of 31° , and including parts twinned after the law *b*. Upon $\infty P (l)$, the composition face, this law cannot be identified.

Law *e*.—Twinning plane — $\frac{1}{2} P (l)$, axis the normal upon it, composition face irregular.

This law seems required to account for certain relations frequently seen upon $\infty P (r)$ and $\infty P (l)$. Upon the former the usual structure of this face appears at right angles to its proper position, while upon $\infty P (l)$ horizontal bands may be seen which are polysynthetic, and give extinction at 45° from position I. This would be explained by the law above given, and is illustrated by Figs. 7 and 8.

Of the above laws the first seems to be identifiable in all portions not parallel to the twinning plane, and the second is nearly as persistent. Law *d* affects substance already twinned after laws *a* and *b*, while *c* and *e* produce a twinning of matter showing *a*, *b*, and *d*. Laws *c*, *d*, and *e* are thought to be justified, for however irregular their composition face, the position of the parts twinned after *a* and *b* is always a very definite and regular one with reference to corresponding parts in the primary individual.

Whether the prismatic twinning plane is right or left, it is clear that the planes of laws *b* and *e* and the composition face of *c* lie in the zone between the prismatic twinning plane and $0P$, and that the plane of *d* is in the zone of $0P$ to the other prism plane.

No twinning parallel to $0P$ was noticed, unless a horizontal division of a few laminae twinned after *a* be thus interpreted (Fig. 8).

CHEMICAL COMPOSITION.—For all analyses of this and the following minerals the greatest care was taken to have the purest of reagents. The fluorine was in all cases determined by the Wöhler-Fresenius method, with the slight modifications introduced by Brandl,²⁵ except that the iron plate instead of the oil-bath was used for heating. The sulphuric acid was obtained of the highest degree of concentration and purity by distillation from a platinum retort. The water was determined by absorption in a chloride of calcium tube, the mineral having been heated in a tube with either oxide of lead or carbonate of sodium, the results being the same whether one or the other was used.

The cryolite, of which the analysis is here given, possessed the specific gravity 2.972 at 24° C., was faintly pink in color, and contained as a visible impurity the oxide of iron represented in the analysis:

XXV.	
Fe ₂ O ₃	0.40
Al	72.81
Ca	0.28
Na	53.46
H ₂ O	0.30
F	53.55
	99.74

(W. F. Hillebrand)

^a As the mean of 53.35, 53.46, 53.55, and 53.85.

The presence of a slight amount of water indicates incipient alteration, but although purer and fresher material was subsequently obtained, a second analysis seems unnecessary.

ALTERATION OF CRYOLITE.—Although pure and fresh cryolite is common, the greater part of masses so near the surface is naturally changed. In the Eureka tunnel the surfaces seen upon the walls exhibit plainly the three cleavage directions of cryolite, especially when moistened. The material is chiefly massive pachnolite, however, as can be distinctly seen in thin sections, while fresh cryolite is still visible in small patches. Alteration of the cryolite proceeds in two ways, producing the same minerals in the end. By one process the principal cleavage fissures are utilized by the solutions which effect the change, and thin walls are formed of a white crystalline substance. The next step seems to be the bodily removal of the cryolite matter between these walls, leaving a network of partitions in the three directions of the chief cleavages of the original cryolite. These partitions or walls are lined by minute crystals. The second mode of alteration proceeds from the neighboring quartz and from the boundaries of the different crystalline individuals of the cryolite, the result being a compact crystalline mass of a faint bluish tinge. The material at hand illustrates the two processes and their products about equally well, and they are often combined.

²⁵ Annalen der Chemie und Pharmacie, CCXIII, p. 1.

²⁶ If Al=27. In this and all subsequent analyses, percentages of aluminium are calculated with the assumption of 27 as its atomic weight.

A large part of the material in the Eureka tunnel is a massive mixture of indistinguishable compounds, probably derived from the alteration of pachnolite. Fluorite is one of the further products, but never appears prominently.

The small mass of fluorides struck in the incline near the Eureka tunnel is remarkable for the purity of a number of further products. Near the quartz and granite walls decomposition has progressed until a pure white substance has been formed, which, when dry, is a kaolin-like powder of extreme fineness. It resembles plaster of Paris when wet, as it invariably is in the vein. This is the greaksutite to be described further on. From this same small mass were obtained most of the specimens utilized in the determinations of the species whose consideration follows.

PACHNOLITE.

FROM THE THIN WALLS.—The microscopical examination of the walls and membranes produced by the first mode of alteration of the cryolite, shows them to be coated by many minute but perfect, colorless, and transparent prismatic crystals, which are usually placed at right angles to the central plane of the wall, though sometimes in an irregular manner. They reach a maximum length of 2^{mm} by a thickness of 0.2 to 0.4^{mm} . The crystals are occasionally yellow in color while retaining their transparency, the color being doubtless owing to some matter derived from the alteration of the astrophyllite which penetrates all such specimens. The crystallographical identification of these crystals with pachnolite is quite certain, for upon placing them in vertical position under the microscope the prism angles can readily be measured, and correspond closely to $81^{\circ} 24'$ and $98^{\circ} 36'$, the theoretical angles of pachnolite (see Groth, l. c., p. 463). The prism ∞P and base $0P$ are in all cases the chief faces, accompanied frequently by a hemi-orthodome and very rarely by a clinodome, both very slightly developed. The former is considered to be $-P \infty$, from data given below. Pyramid faces have not been seen upon crystals of this growth. Although all detached crystals show, when examined in polarized light as lying upon a prism face, an oblique twinning plane in the prismatic zone,²⁷ still a projecting angle upon the base can but rarely be seen. The reflecting surfaces of the thinnest walls are composed of innumerable small facets of rhombic outline,—the basal planes of the very low prisms. In fragments from some of the thinnest walls, placed horizontally under the microscope and observed in polarized light, twinning parallel to the shorter (ortho-) diagonal can easily be seen. The crystals are usually quite equally bisected by the twinning line. The central portion of these walls is rather dull white, and probably represents the alteration product on cleavage planes of the original cryolite, while the crystals

²⁷ Groth, l. c., p. 464.

themselves were formed during or after the removal of the intermediate cryolite substance. Material from a network of thin walls covered by pachnolite crystals was subjected to chemical analysis, yielding the result under XXVII, p. 54.

FROM THE BLuish MASSIVE ALTERATION PRODUCT.—The pale bluish mass formed by the second mode of decomposition has, in great part, a regular crystalline structure produced by a more or less perfect intergrowth of pachnolite individuals in three directions approximately at right angles to each other. Nearly simultaneous reflection over the greater part of certain irregular surfaces make this relation plain. By the examination of such a surface with a lens one can usually identify a number of rhombic facets which are nearly or quite coincident in position with striated planes, the two corresponding to OP and ∞P of different individuals. Such a structure is also illustrated by the crystals in the numerous small cavities occurring in the massive material.

These cavities are wholly of irregular shape and reach a maximum observed diameter of 3 to 4^{mm}. The crystals lining them are often very perfect, and are occasionally 2 to 3^{mm} in length, with a thickness of 1^{mm} or less. The study of these crystals proves that, as in the preceding case, most of them must be referred to pachnolite, although thomsonolite is sparingly present. These pachnolite crystals differ in habit from those already described in that the pyramid is usually prominent, being, however, in nearly every case truncated by the basal plane; in fact, crystals without OP are very rare. The rhombic section of the prism is everywhere plain. Although every prism on being optically tested shows a twinning plane in the prismatic zone, the low projecting angle of $179^{\circ} 20'$ upon OP can seldom be distinctly seen. Many crystals are somewhat extended parallel to one pair of prism faces. A hemi-orthodome of the same order as the pyramid is sometimes developed, and probably corresponds to that noticed upon the crystals of the foregoing type. Most of the crystals of these cavities, while very perfect and distinctly recognizable as pachnolite, are too small and their surfaces are too frequently covered by minute crystals of a later growth to be available for measurements with the goniometer. Two specimens, however, of the bluish massive material, when carefully examined, proved to contain pachnolite in a form allowing of more exact crystallographical, optical, and chemical investigation.

CRYSTALLOGRAPHICAL DETERMINATIONS.—The first of the specimens above mentioned, which we will designate specimen A, is about $8 \times 5 \times 2$ ^{cm} in size, is somewhat more coarsely granular than the variety just described, and possesses in an eminent degree the regular structure there observed. While compact in the greater part of the specimen, there are portions in which the grains are more loosely aggregated together, and parts of individuals have perfectly developed crystal faces. In some minute cavities a few crystals with quite perfect terminations

were found, and upon these some faces were sufficiently large and polished to admit of measurements with a Fness reflection goniometer. These crystals are about 1^{mm} long and nearly the same in thickness. They show ∞P , $0P$, with subordinate $-P$, and a negative pyramid determined, as $-3P\bar{3}$. They are all twinned parallel to $\infty P\bar{\omega}$, and the low projecting angle upon $0P$ is sometimes distinctly visible.

The angles given in the following table are all means of numerous closely agreeing measurements and demonstrate the crystallographical identity of the mineral under discussion with pachnolite:

Angle.	Crystal a.	Crystal b.	Other crystals.	Calculated.
	° ' "	° ' "	° ' "	° ' "
$\infty P \wedge \infty P$	81 19	81 22	81 18	81 24
$P \wedge 0P$		90 31	90 21	90 20
$-P \wedge 0P$		116 39	116 30	116 30
$-3P\bar{3} \wedge -3P\bar{3}$	138 45		138 45	138 52 14
$-3P\bar{3} \wedge \infty P$	149 03			149 07 19
$0P \wedge 0P$ (twin)		179 21		179 20

The face $-3P\bar{3}$ was observed on a number of distinct twin crystals, with projecting angle on $0P$, and in several cases on both of the negative angles.

Upon one side of specimen A are a few thomsenolite crystals, distinguishable by their prism angle of nearly 90°. They lie irregularly, and seem to be later in formation than the pachnolite. Upon them are deposited minute prosopite crystals and indistinct alteration products. In the mass of this specimen no thomsenolite can be detected, while all individuals with partially free development are plainly pachnolite. Analysis XXVIII of the table (p. 54) was made upon material obtained from the clear loosely granular portions of specimen A, and although it was necessary to include many transparent grains of irregular shape, in order to obtain a desirable amount of substance, there is no doubt in our own minds that thomsenolite was wholly absent from the material analyzed.

The second specimen, B, from which especially good material was obtained, had a seam 2^{cm} thick of coarse granular structure running through it, and upon splitting it open along this seam two surfaces of water-clear loosely adhering crystalline grains of pachnolite were exposed with the regular arrangement described. Actual development of crystal faces other than the prism is rarer than in specimen A, but the size of the grains, reaching 5^{mm} in length by 1—3^{mm} in thickness, is such as to admit of the preparation of thin sections for optical examination, and also gave absolutely pure material for chemical analysis. None of the crystals upon which the faces were well formed were superior to those of specimen A, and only measurements of the prism angles were made. The face $-3P\bar{3}$ was not observed at all.

The optical properties of these pachnolite crystals are such as to leave no doubt concerning their crystallographical identity with the

mineral described by Professor Groth as pachnolite. Several sections were prepared as nearly parallel to the clinopinacoid as possible. These exhibit in all cases a twin structure, and this is frequently polysynthetic. The twinning lines are straight and lie parallel to the vertical axis. Extinction takes place at $21^{\circ} 30'$ to 22° , or 68° to $68^{\circ} 30'$ from the twinning line, in opposed directions in alternate laminae. According to Groth the bisectrix is in the plane of symmetry, and inclined $68^{\circ} 5'$ forward from the vertical axis. Sections parallel to the base also show the twinning structure, the line lying parallel to the orthodiagonal.

A large part of the purest crystals and fragments from this specimen were used for chemical analysis and repeated water determinations, the results of which are given below (XXIX, p. 54).

CHEMICAL INVESTIGATION.—Previous to the analysis by Brandl²² of pachnolite carefully selected by Groth, pachnolite and thomsenolite were considered to possess the same chemical composition. The results of all earlier analyses, excluding such as referred to manifestly very impure material, while frequently deviating materially from the figures required by theory for the formula NaF , CaF_2 , AlF_3 , H_2O , still agree on the whole very well, as shown in the accompanying table, and fully justified the belief in the chemical identity of the two species.

	Thomsenolite.		Pachnolite.					Calculated for NaF, CaF ₂ , AlF ₃ , H ₂ O
	Wöhler. ²⁰	König. ²⁰	Knop. ²¹	König. ²⁰	Vom Rath. ²²	Hage- mann. ²³		
Al	13.43	13.74	13.14	12.50	13.46	12.93	10.37	12.22
Ca	17.84	16.79	17.25	18.17	18.10	17.09	17.44	17.78
Na	10.75	10.10	*12.16	10.23	10.63	12.06	12.04	10.34
H ₂ O	8.20	9.00	9.60	8.19	.....	.....	8.63	8.10
F	49.78	50.37	50.79	51.54	.....	.....	51.15	51.26
	100.00	100.00	102.94	100.63	.....	.. ..	99.63	100.00

* Also, 10.80 and 10.81.

Wöhler's analysis was entirely confirmed some years subsequently by Jannasch,²⁴ in Göttingen, who analyzed pure thomsenolite selected by Klein.

In view of the above, the analysis of pachnolite by Brandl, showing results agreeing well with those required by the formula NaF , CaF_2 , AlF_3 , was calculated to cause no little surprise. Groth accepts without question the anhydrous nature of pachnolite, and endeavors to explain

²⁰ Annalen der Chemie und Pharmacie, CCXIII, p. 6.

²⁰ Neues Jahrbuch für Mineralogie, etc., 1876, p. 851.

²⁰ Proceedings Acad. Sci. of Phila., 1876, p. 42.

²¹ Annalen der Chemie und Pharmacie, CXXVII, p. 61.

²² Sitzungsbericht d. niederrhein. Ges. für Natur- und Heilkunde, 1860, XX, p. 141.

²³ Am. Jour. Sci., 1866, II, XLI, p. 119.

²⁴ Neues Jahrbuch für Mineralogie, etc., 1877, p. 808.

away the opposing evidence, shown in the foregoing table, by assuming that the supposed homogeneous material analyzed was contaminated largely with thomsenolite. As in no published analysis does the percentage of water fall below 7 per cent., this assumption necessitates a most improbable admixture of thomsenolite. In those cases where the percentage of water equals or exceeds that required for thomsenolite the presence of gearksutite is suggested by Groth as a possible explanation. Even on this supposition the percentage of foreign admixture could not fall below 50 per cent., in which extreme case the whole of the impurity must be gearksutite, an amount which it is difficult to conceive should have escaped the notice of such observers as König, vom Rath, and Knop, the latter of whom expressly says that his analysis was made upon material identified as pachnolite.³⁵ Notwithstanding the difficulty of explaining the agreement between the previous analyses of pachnolite and thomsenolite, on the assumption of the anhydrous nature of the former, the correctness of Brandl's analysis was not at first questioned by us.

In the course of the present investigation the compact bluish material (see page 50), having the specific gravity 2.980 at 22° C., was first analyzed, the crystalline pachnolite not having yet been observed. The results of analysis as given under XXVI, below, agree in the main so well with the figures required for the formula NaF , CaF_2 , AlF_3 , H_2O , that no hesitation was felt in considering the mineral to be thomsenolite, probably slightly contaminated with fluorite. Later, the crystalline coating on the thin walls produced by the first mode of alteration of the cryolite, the crystals forming which had not yet been identified crystallographically as pachnolite, were subjected to analysis with the results given under XXVII. Here again the identity with thomsenolite seemed clear. It was not until the analysis of perfectly transparent fresh crystals and crystal fragments, all taken from specimen A, above described, gave the results shown under XXVIII, that the possibility of the first analyses having been also made upon pachnolite was suggested. That this was, however, so in the case of No. XXVII, subsequent careful examination fully revealed, though the crystals analyzed were not entirely free from foreign admixture. It seems certain, also, that the compact bluish portions (XXVI) consist almost entirely of pachnolite, although it cannot be positively asserted that some thomsenolite may not be intergrown with it. That no possible doubt might exist in the mind of any one as to the homogeneity of the material used for analysis XXVIII, a further analysis was made upon crystals from specimen B, above described, particular care being taken to identify each as pachnolite by the rhombic section. The results of this analysis appear under XXIX.

³⁵Neues Jahrbuch für Mineralogie, etc., 1876, p. 850.

	Hillebrand.								Calculated for NaF, CaF ₂ , AlF ₃ , H O
	XXVI.		XXVII		XXVIII.		XXIX.		
Al.....	11.94		12.96	12.92	12.14		12.27	12.51	12.16
Ca.....	19.32		15.27	15.17	18.06		18.04	18.83	18.12
Mg.....	0.13		1.53						
Na.....	10.43		10.28		10.23		10.25	11.73	10.38
K.....			0.13						
H ₂ O.....	7.87	7.96	8.64	8.79	8.10	8.11	8.05		8.11
F.....					51.33	51.28	*51.39	55.09	51.35
					99.88		100.00	99.76	100.00

*By difference.

Further determinations of water, on material from specimen B, gave 7.95, 7.99, 8.14, and 8.15 per cent. Still other determinations, some on material every fragment of which showed the rhombic section, others on material taken at random from the crystalline mass, gave results between 7.90 and 8.20 per cent. The specific gravity at 17°C. of the perfectly pure material, as the mean of four determinations varying between 2.963 and 2.968, was 2.965. A single determination on another portion, equally pure, at 22°C. gave 2.962. The transparent crystals, as well as all the other portions analyzed decrepitated violently on heating in a test tube, the walls became lined with the white deposit so characteristic of thomsenolite and pachnolite, and much water was given off. Hence it appears that the pachnolite from Pike's Peak and thomsenolite are identical in composition, unless the fact of all analyses of thomsenolite showing slightly more water than required for the formula NaF, CaF₂, AlF₃, H₂O may indicate, as suggested by Groth, a partial replacement of fluorine by hydroxyl in that mineral. Should this prove to be the case, a plausible explanation of the difference in crystallization of the two minerals is offered without recourse to the theory of dimorphism.

A satisfactory explanation of Brandl's results, so opposed to those presented by all earlier analyses and the ones above given, is impossible, but it may be well to call attention to the fact that Brandl was obliged to make his determinations of fluorine and the metals upon quantities of 0.1106 gr. and 0.1430 gr. weight respectively, whereas material was not wanting for the present analyses, the determinations having been made upon weights of from 0.3 gr. to 0.75 gr. It nowhere appears that a direct test for water was made upon the material furnished by Groth. The latter, it is true, remarks (l. c. p. 461): "*Ausserdem bildet sich bei letzterem (Thomsenolite) in den kälteren Theilen des Rohres ein Wasserbeschlag, welcher beim Erhitzen reinen 'Pachnolithes' natürlich ausbleibt.*" The absence of water does not, however, seem to be hereby proven, but simply to be assumed from the close approximation to 100 of Brandl's results, exclusive of water. Brandl himself says water is wanting, but does not mention whether this was ascertained

* Annalen der Chemie und Pharmacie, CCXIII, p. 6. The percentage of Al is calculated to correspond with the other analyses (Al=27).

by direct experiment. The small amount of material at his disposal renders it not improbable that no direct test was made.

Since the conclusion of the above investigations, through the kindness of Mr. Albert F. Damon, president of the Pennsylvania Salt Manufacturing Company, we have obtained specimens of Greenland cryolite and its alteration products. From one of these specimens was removed a large number of small, needle-like, pyramidally terminated, twinned crystals with a rhombic prismatic section, showing in fact precisely the common occurrence³⁷ and ordinary habit of pachnolite³³ as described by Groth. These crystals, slightly yellowish in color, but quite transparent, were individually examined under the microscope, all such as did not show beyond a doubt the above described habit being excluded. They were then tested in a small glass tube for water. Decrepitation ensued on heating and the walls of the tube became lined with a white powder, and also with a deposit of water, in such quantity as to preclude the possibility of its having been derived from but a small portion of the material experimented upon.

OTHER FORMS OF PACHNOLITE.—In some very cellular specimens, whose walls run irregularly and seemingly without reference to the cleavage of the original cryolite, are crystals of pachnolite of different habit from that so far described.

One or two of these cavities show crystals corresponding in size to those upon the thin walls, but exhibiting each and every one a re-entering angle on the free termination. In such little crystals the basal planes are prominent, and they are bounded on the inside by a pyramid and dome, doubtless $-P$ and $-P\bar{\infty}$. Outward there sometimes appears another pyramid ($+P?$), though the prismatic faces themselves usually form a sharp edge with $0P$. All these crystals are too small for measurement, but as the appearance described is such as would be normal for the termination by which the twin crystals are commonly attached, it seems admissible to consider the faces as $0P$, $-P$, $-P\bar{\infty}$ and probably $+P$. On many twins of this kind the outer or positive angles between ∞P and $0P$ are replaced by two faces greatly resembling those of $-3P\bar{3}$, and although entirely too minute for measurement it is probable that this form $-3P\bar{3}$ is here represented. The crystals of Greenland pachnolite are always attached by the end with the re-entering angle, according to Groth.

THOMSENOLITE.

OCCURRENCE AND DESCRIPTION.—While it is quite certain that thomsenolite is present in small quantity with the pachnolite, it has been impossible to obtain any quantity of it for examination. The microscopical study of the minute crystals lining the thin walls described, shows a few of nearly square section with sharp pyramidal form and destitute

³⁷ P. Groth, *l. c.*, p. 461.

³⁸ P. Groth, *l. c.*, p. 462.

of a twin structure. These are usually deposited with corresponding ones of pachnolite in a wholly irregular manner upon the low crystals of pachnolite forming the main portion of the walls. The reflecting surfaces of the massive product show under the lens distinctly rhombic facets or striated planes; and thin sections, which reveal the characteristic twinning of pachnolite, afford no reason for suspecting the presence of thomsenolite here in any considerable quantity.

The statement already made for a single case (p. 51) is probably true for all cases where thomsenolite has been noticed, viz., that it is later in formation than the greater part of the pachnolite, although the latter mineral is usually present in a second generation, as contemporary with the thomsenolite. No chemical identification has been possible, but the nearly square section, perfect basal cleavage, and absence of twinning are under the circumstances quite sufficient proofs.

In many cavities, arising from both modes of decomposition of the cryolite, a second series of minerals has been deposited, chiefly as a whitish, easily crumbling aggregate of minute crystalline grains, which are recognizable under the microscope as thomsenolite, pachnolite, and a mineral of the isometric system. The difference in habit of the former two species is here quite plain, for some of the little crystals of thomsenolite are doubly terminated and show distinct monoclinic symmetry in spite of the square section, through the more prominent development of the negative pyramid, while pachnolite seems perfectly rhombic in form, through its twinning.

RALSTONITE.

PROBABLE IDENTIFICATION.—This rare species, originally described by Brush,³⁹ from microscopic crystals, has been more definitely determined by Groth and Brandl. Its chemical composition is, according to Brandl, expressed by the formula 3NaF , 4AlF_3 , H_2O , a small part of the sodium being replaced by calcium. The crystals are of the isometric system, and represent the cube modified by the octahedron.

Groth's description of the occurrence of the mineral agrees very closely with that of the isometric mineral mentioned above as appearing with a recent generation of thomsenolite and pachnolite. The crystals here found are transparent cubes whose corners are replaced by small octahedron faces and seldom reach a diameter of 1mm , while sinking to microscopic size. Some crystals of pachnolite seem by a low magnifying power to be coated by a crystalline dust whose particles are found, by applying a high power, to be most perfect little crystals of the form just mentioned. These sometimes unite to form a crust. No material for a chemical test could be secured, but the analogy in form and occurrence is so complete that scarcely a doubt can exist of the identity of these beautiful little crystals with the species ralstonite, although another mineral of the same crystal system is now to be described.

³⁹ G. J. Brush, *Am. Jour. Sci.*, III, II, 30, 1871.

ELPASOLITE, A NEW MINERAL.

Just at the close of our investigations a mineral was found, occurring sparingly in a few specimens, which seems to be very different from any known species. It was found in small cavities in the massive pachnolite as a compact irregular mass, colorless but not perfectly clear, and exhibiting but seldom traces of crystalline form. In one specimen, however, the mass of the mineral was covered by small rounded crystal-like projections, which seemed like crystals of the isometric system. An examination with a loupe showed the absence of recognizable faces, but such particles when broken off and tested under the microscope proved to be fully isotropic. A few faces found on one crystal seemed to belong to cube and octahedron, and particles detached from the same are isotropic in action in polarized light. Supposing that this substance must be ralstonite in exceptional development, enough material for the following partial chemical analysis was selected, being carefully freed from attached particles of pachnolite and other anisotropic minerals by microscopical examination. The Al, Ca, and Mg were accurately determined, the K and Na, owing to an unfortunate mishap, only approximately. No water could be detected by direct test upon a small portion. Fluorine was present in quantity, and the percentage given below is calculated on the assumption that the metals are fully combined with it:

	XXX
Al	11.32
Ca	0.72
Mg	0.22
K	23.04
Na	9.90
F	46.98
(W. F. Hillebrand.)	98.08

From this analysis may be derived a formula analogous to that of cryolite, in which about two-thirds of the sodium is replaced by potassium.

The imperfections of the above analysis do not allow of definite conclusions as to the composition of the mineral, but it is nevertheless widely different from any known mineral species, while the purity of the substance is shown by its isotropic action in polarized light. Since the original description of the mineral⁴⁰ the locality has been revisited in the hope of obtaining more material, but the spot was at the time inaccessible, so that we can offer no further data concerning this interesting new species. We wish to propose the name *elpasolite* for it, from the county El Paso, which embraces the greater part of the Pike's Peak region. Further investigations as to the properties of the mineral will be made as soon as material can be procured.

⁴⁰ Am. Jour. Sci., III, XXVI, 283, 1883.

GEARKSUTITE.

GENERAL DESCRIPTION.—This mineral, first observed by Hageman⁴¹ on compact thomsenolite, and described as earthy and kaolin-like in aspect, dull white, opaque, and of hardness 2, seems to be so rare in connection with the Greenland fluorides that no one has had material for further examination. Groth⁴² found it in very small quantity among the minerals at his disposal, but could not obtain enough for analysis. He found, however, that it consisted of very minute microscopic needles, with oblique extinction, and considers it as undoubtedly a definite species.

Among the minerals from St. Peter's Dome gearksutite is quite abundant. It is not formed from other minerals by molecular replacement, but is deposited from solution in cavities upon fresh crystals of pachnolite, etc. The smaller cavities are sometimes filled by it, and on the contact with the quartz it is specially developed.

In appearance it corresponds closely to the description of the Greenland mineral as given by Dana, the resemblance to the purest, finest kaolin being especially remarkable. Examined microscopically, gearksutite is seen to consist, as stated by Groth, of exceedingly minute colorless needles, the average length of which is less than 0.02^{mm} and the thickness less than 0.002^{mm}, and apparently possessing oblique extinction.

CHEMICAL INVESTIGATION.—Gearksutite was found by Hagemann (*l. c.*) to possess the following composition :

Al	15.52
Ca	19.25
Na	2.46
H ₂ O	20.22
F	41.18
	—
	98.63

An examination of the above results shows that the atomic ratio of Al:Ca+Na₂:F is 1:1:4, instead of 1:1:5, which would represent complete saturation and require about 12 per cent. more fluorine than was found. On the assumption that the missing fluorine is replaced in the mineral by oxygen or hydroxyl, there should appear a much greater loss than the analysis indicates. An error is therefore evident, probably in connection with the determination of the fluorine or of the water, or both, in consequence of which the construction of a satisfactory formula has heretofore been impossible.

The material for the following analyses was first partially crushed, then freed from admixed heavier particles of foreign matter by triturating in a beaker with water, the impurities falling to the bottom of the vessel, while the light gearksutite remained suspended in the liquid

⁴¹ Dana, System of Mineralogy, 5th ed., p. 130.

⁴² Groth, *l. c.*, pp. 460, 481.

and was removed by decantation. By repeating this operation a great many times a product was finally obtained entirely free from all foreign admixture. It was allowed to settle completely, the supernatant liquid poured off and the residue dried first on the water bath, then at 100° C. Thorough pulverization of this residue is a difficult matter, as it flattens out under the pestle, forming flakes which strongly resist the pulverizing action. This is of little moment, however, since the flakes are so spongy as to offer no hindrance to attack by sulphuric acid. Two analyses were made from the same sample, with the results tabulated below. In *b* sodium and potassium were not determined:

	XXXI.		
	a.	b.	Mean.
Al	15.22	15.19	15.20
Ca	22.29	22.32	22.30
Na	0.10	.....	0.10
K	0.04	.....	0.04
H ₂ O	15.54	15.89	15.46
F	42.14	42.01	42.07
	95.23	.....	95.17
Loss as O	4.67	.....	4.53
	100.00	.....	100.00
(W. F. Hillebrand.)			

Taking the figures in the third column and combining the fluorine with the calcium, sodium, potassium, and, as far as possible, with the aluminium, there remains of the latter 5.35 per cent., requiring 4.76 per cent. of oxygen, an amount agreeing very well with that obtained above by difference and making the sum total almost exactly 100:

22.30 Ca	requires 21.18 F.
0.10 Na	requires 0.08 F.
0.04 K	requires 0.02 F.
9.85 Al	requires 20.79 F.
10.11 Al ₂ O ₃	.....
15.46 H ₂ O	42.07
42.07 F	.....
.....	
99.93	.....

The agreement of the above analysis with that of Hagemann, after substituting in the latter for the sodium its equivalent in calcium, is very close, with the single exception of the water. As his analysis was manifestly erroneous in some particular, the assumption of the identity of gearksutite with the mineral here discussed is fully justified, supported as it is by the similarity in occurrence, appearance, and physical characteristics. His error would then consist in having obtained from 4 to 5 per cent. too much water, a result not difficult of explanation in

the case of a hydrated fluoride, if no precaution was taken to prevent the escape of fluorine.

Substituting in the mean of analyses *a* and *b* for sodium and potassium their equivalent of calcium, and dividing the percentages by the atomic weights, the atomic ratio is found to be as given below :

Al	.....	15.20 ÷ 27 = 0.563
Ca	.....	22.41 ÷ 40 = 0.560
H ₂ O	....	15.46 ÷ 18 = 0.859
O	.....	4.76 ÷ 16 = 0.297
F	.....	42.07 ÷ 19 = 2.214

The ratio of Al : Ca : F is here nearly as 1 : 1 : 4, the same as found by Hagemann. Subtracting from the atomic value for water an amount 0.297 equal to that for oxygen, in order to form with the latter hydroxyl, the result is as given in the first column below, while in the second appears the ratio referred to calcium as unity.

Al	.....	0.563	1.005	
Ca	.....	0.560	1.000	
H ₂ O	.....	0.562	1.004	
HO	.....	0.594	1.061	} 5.015
F	.....	2.214	3.954	

It will be seen that by combining hydroxyl and fluorine the ratio Al:Ca:H₂O:(F,OH) is 1:1:1:5, and the formula for the mineral becomes CaF₂, Al(F, OH)₅, H₂O, in which the fluorine and hydroxyl combined with the aluminium, stand nearly as 2:1. Were the latter proportion exactly fulfilled, the formula might be written 3CaF₂, 2AlF₃, Al(OH)₃, 3H₂O, requiring the percentages: Al 15.17, Ca 22.47, F 42.69, O 4.50, H₂O 15.17 = 100.00.

Of the 15.46 per cent. of water found by analysis, 5.35 per cent. has been considered in the foregoing as basic. While this amount may, on theoretical grounds alone, enter into the inner constitution of the mineral as basic water, the remainder cannot, but must be water of crystallization. That a portion of the water is basic is rendered more than probable by the fact that at 300° C. some is still retained. In this connection the following experiments were made: 0.5677 gram of the mineral, not, however, from the same sample as that used for analysis, dried first at 100° C. and contained in a platinum crucible, was exposed in an air bath during 145 hours to temperatures ranging from 100° C. to 300° C., the weight being taken at intervals averaging 10 hours each. The results in brief showed that at 145° C. the loss was but 0.35 per cent., at 230° C. only 0.92 per cent., at 250° C. 7.02 per cent., after prolonged heating at 265°–270° C. 9.49 per cent., and at 295° C. 13.92 per cent. As no further loss occurred after six hours heating at 295°–300° C., a portion of the residue which still retained its original appearance was subjected to a quantitative test for water, of which 1.76 per cent. was found.

This added to the 13.92 per cent. driven off below 300° C. made the total 15.68 per cent. Since this is slightly higher than the mean of the previous results, it seemed possible that some fluorine might have escaped. The remainder of the residue was therefore tested quantitatively for fluorine, of which was found 40.60 per cent., thus apparently proving the correctness of the surmise. A similar experiment with the same general results was made upon a smaller portion of another sample. A comparison of the full results of both experiments showed that by sufficiently prolonged heating at approximately 270° C. all the water of crystallization could be driven off; also that by still further heating at little if any higher temperature the basic water began to escape, but was not entirely expelled even after many hours exposure to a temperature of 295° – 300° C.

While these experiments cannot be considered as affording any conclusive proof that the water in this mineral is to be reckoned as water of crystallization and basic water in the above given proportions, since at the point when the last of the former is driven off by heat some of the latter appears also to escape, still the belief that this should be done is a natural one and is supported by the fact (which may possibly, however, be merely the result of accident) that by so doing the ratio of calcium to water of crystallization is exactly 1:1, while if all the water is assumed to be water of crystallization the ratio is 1:1.534 or 2:3.068.

EVIGTOKITE.—In the Journal of the Chemical Society for 1883, p. 140, Walter Flight describes a mineral obtained from the cryolite bed of Greenland. "It is made up of a congeries of minute white transparent crystals, mostly broken up and lying entangled among each other in every sort of direction, which gives the mass an appearance of opacity much resembling that of kaolin or chalk."

Chemical analysis showed it to consist of—

	Equivalents.
Al. 16.23 with F 33.64 = 49.87	0.59
Ca. 22.89 with F 21.27 = 43.66	1.12
Na. 0.43 with F 0.33 = 0.76	
	94.29
Water	5.71
	100.00

The fluorine seems to have been calculated for the metals, and the water was found by difference.

From the above data the author obtains the formula 2CaF_2 , Al_2F_6 , $2\text{H}_2\text{O}$,⁴ and, considering the mineral new, names it evigtokite.

Mr. Flight seems to have overlooked the description of gearksutite in Dana's System of Mineralogy and Professor Groth's remarks upon the same (l. c., pp. 481 and 493), else the very fair agreement of his analytical data for the metals with those of Hagemann, and the similarity of oc-

⁴ Probably a printer's error. It should read 2CaF_2 , Al_2F_6 , H_2O .

currence, appearance, and physical characteristics of the two minerals, must have led to at least a suspicion of their identity. There can hardly exist a doubt that Flight has analyzed gearsutite and that the name evigtokite is therefore to be dropped.

PROSOPITE.

OCCURRENCE.—This rare species, hitherto unobserved in association with the cryolite minerals and known only in connection with the tin-bearing veins of Altenberg in Saxony, has been identified at St. Peter's Dome.

Both of the coarsely crystalline specimens of pachnolite, above described as A and B, have prosopite upon them. Specimen B is in parts in process of alteration to a dull white substance with little cavities in which are minute crystals of prosopite. These are colorless, transparent, tabular in shape, agreeing exactly in form and optical behavior with those determined as prosopite by chemical analysis. In two other specimens of pachnolite prosopite tablets may be seen upon certain granular surfaces when decomposition of the pachnolite has already begun. The crystals are usually attached by the prismatic edges, although free and perfect terminations are to be found. Gearsutite was noticed upon them in one specimen and the position of prosopite in the series of hydrous fluorides is doubtless between thomsenolite and gearsutite. No material for chemical tests could be procured from the specimens described.

The penetration of the fluoride mass by astrophyllite blades springing from the side of the vein has been mentioned (p. 42). Here the cryolite has been altered to cellular pachnolite, according to the first mode described, and this has for the greater part given way to other products and been dissolved and carried away, leaving the astrophyllite blades more or less free or imbedded in gearsutite and other soft, crumbling material. The free blades usually have a coating composed of a little purplish fluorite, and over this a nearly colorless or slightly yellowish substance. At and toward the base of the astrophyllite blades the latter is present in roundish aggregates made up, as shown by the lens, of clear tablets, in more or less radiate arrangement. The crystal form is here quite obscure, but the general appearance was so suggestive of prosopite that by sacrificing the best specimen enough material was obtained for determination of the bases and of fluorine, with the result given below, XXXVI, p. 64.

Adjoining the quartz in the Eureka mine is usually an irregular zone of purplish or greenish fluorite, and next to this a rather coarsely granular mass of a colorless mineral, with two distinct cleavage planes, which passes gradually into the compact white substance beyond. This zonal arrangement is not without exceptions, for both granular and compact masses come directly in contact with the quartz in some specimens, and fluorite is more or less abundantly sprinkled through the

other substances; in fact, the relation of the minerals to each other is such as to indicate that they are but different phases of alteration from a common source. The granular mineral occurs in sufficient purity to afford material for chemical analysis, and its individuals are large enough to admit of the preparation of thin sections, with definite relations to the cleavage planes. The analysis first proved the identity of this mineral with prosopite, the optical properties shown by the thin section confirmed this determination, and a few minute crystals were found in one specimen, which agree with the published data on the Saxon mineral. As the identification of this rare species, particularly in its present association, is a matter of considerable interest, we will describe it somewhat in detail.

CRYSTALLINE FORM AND PHYSICAL PROPERTIES.—The minute crystals observed are all of the habit shown in Fig. 11 of the plate. This is from a camera lucida drawing of a crystal measuring 0.5^{mm} normal to the edge of the prism, and can therefore make no pretensions to crystallographic accuracy. The crystals are colorless and transparent, have uniformly a tabular form through the development of $\infty P \infty$, and show plainly the prism and two pyramids, which may be considered as P and $-2P\bar{2}$, for extinction takes place nearly or quite parallel to the edge of $-2P\bar{2}$, which is, according to Des Cloizeaux⁴⁴ and Groth,⁴⁵ the position of the bisectrix.

Thin sections prepared as nearly as possible perpendicular to the edge of the two cleavage faces in the irregular granular individuals, show that the angle of the cleavage planes is very nearly 135° , and that extinction takes place parallel to the direction bisecting that angle. This behavior agrees perfectly with the statements concerning prosopite, according to which the chief cleavage is parallel to $-2P\bar{2}$, the angle of which is about 134° . The present material does not allow of a definite settlement of the question of the crystalline form of prosopite, but nothing observed is in conflict with the reference to the monoclinic system.

CHEMICAL INVESTIGATION.—The formula deduced by Brandl⁴⁶ for prosopite, from the results of his analysis as here given—

		Atomic values.
F	35.01	1.842
Al	23.87	0.953
Ca	18.19	0.405
Mg	0.11	0.004
Na	0.33	0.014
H ₂ O	12.41	0.689
Loss as oxygen	12.58	0.786
	100.00	

⁴⁴ Bull. Soc. Min. de Fr., V, 317.

⁴⁵ l. c., p. 290.

⁴⁶ Annalen der Chemie und Pharmacie, CCXIII, p. 13.

is $\text{Ca F}_2, 2\text{Al (F,OH)}_2$. The whole of the water is assumed to be basic, entering with oxygen into the constitution of the mineral as hydroxyl, the latter replacing an equivalent amount of fluorine. In support of this assumption Brandl mentions that no loss is perceptible below 260°C .

In an earlier partial analysis Scheerer (Pogg. Ann., CI, p. 361) found Al 22.77, Ca 16.41, H_2O 15.50.

Of the analyses tabulated below, those under XXXII, XXXIII, XXXIV, and XXXV were made upon material from vein B. That analyzed under XXXII, *a* and *b*, was composed of comparatively large irregular crystalline pieces showing no visible impurity whatever, having a specific gravity at 23°C . of 2.880 and a hardness of about 4.5. As the ratio Al:Ca differed materially from that of 2:1, required by Brandl's formula, it appeared that some foreign matter must be present, consequently no further determinations were made, as it was hoped better material might be obtained.

Analysis XXXIII was made upon material separated from quartz, zircon, fluorite, and other accompanying minerals, by a solution of iodide of mercury in iodide of potassium. The result was a slight improvement, and the analysis was completed. The material for XXXIV was picked out carefully by hand with the aid of a lens, but as the result was still unsatisfactory, a further portion (XXXV), aggregating, however, only 0.1022 gram, was selected with the greatest possible care, every particle being distinctly crystalline, and showing under the microscope no trace of impurity. Here a slight improvement becomes evident in the ratio, but as the amount taken for analysis was so extremely small, it cannot be asserted that the better results may not be due to unavoidable errors of analysis. The material for analysis XXXVI was derived from the crystals occurring on astrophyllite. This material was, however, evidently not quite pure, being opaque and very slightly colored in part by oxide of iron. The analysis was made merely to prove its identity with the prosopite of the other occurrence.

	XXXII.		XXXIII.	XXXIV.	XXXV.	XXXVI.
	a.	b.				
Al	21.94	21.68	21.88	22.13	22.49	21.64
Ca	17.67	17.87	16.92	17.14	16.80	16.84
Mg			0.20		0.15	0.35
Na			0.48		0.48	0.79
K						0.11
H_2O			*13.54			
F			83.14	83.22		32.30
Loss as oxygen			86.16			
			13.84			
(W. F. Hillebrand.)			100.00			

* And 13.37.

The mean of analyses XXXII-XXXV is as follows:

Al.....	22.02
Ca.....	17.28
Mg.....	0.17
Na.....	0.48
H ₂ O.....	13.46
F.....	33.18
Loss as oxygen.....	86.59
	13.41
	100.00

After subtracting from the fluorine an equivalent for the calcium, magnesium, and sodium, and combining the remainder with aluminium, there remains of the latter 14.39 per cent., requiring 12.79 per cent. of oxygen, instead of 13.41 per cent. found by difference. The atomic values appear as follows, after substituting for magnesium and sodium an equivalent of calcium:

Al.....	22.02 ÷ 27 = 0.815	
Ca.....	17.98 ÷ 40 = 0.449	
F.....	33.18 ÷ 19 = 1.746	
H ₂ O	13.46 ÷ 18 = 0.748	} 1.547
O.....	12.79 ÷ 16 = 0.799	
		3.293

The result is unsatisfactory, the ratio of Ca: Al being 1:1.81 instead of 1:2. In none of the material analyzed was the slightest trace of kaolinization to be observed, nor any other foreign matter. It therefore becomes impossible to explain with any degree of certainty the above abnormal results.

The general agreement of all the analyses, the aluminium being found too low and the calcium too high in each case, shows pretty conclusively that an explanation cannot be sought for in analytical errors.

As fluorite occurs here always in most intimate association with prosopite, and the possibility suggested itself that some of this might be so intergrown with the latter as to escape the closest scrutiny, it became desirable to ascertain what change would be effected in the ratio above given by subtracting enough calcium to make the ratio Ca: Al as 1:2, and an equivalent amount of fluorine. The atomic values then become:

Al	0.815	2.00
Ca.....	0.408	1.00
F.....	1.664	} 3.211
HO.....	1.547	
		7.87

which agree nearly as well for the formula $\text{Ca, Al}_2 (\text{F, OH})_8$ as those obtained by Brandl.

If, instead of the mean of all the analyses, the figures of XXXIII alone

are taken for calculations similar to the above, the result is the same, even a little more closely approximating to the ratio 2:1:8.

The prosopite is much less readily attacked by sulphuric acid than the other fluorides described, and unless the pulverization is very thorough a small portion is generally left undecomposed even by boiling acid. To this fact may possibly be due the deficit of nearly 2 per cent. in fluorine, as compared with Brandl's results. On the assumption that 35 represents more nearly than 33.18 the true percentage of fluorine in the mineral analyzed, the ratio of water to required oxygen after combining all fluorine is 1:1.005, instead of 1.068. Allowing, then, for possible admixture of fluorite as above, the ratio $Al:Ca:F+OH$ is 2.00:1.00:7.99, almost exactly 2:1:8.

The observation made by Brandl that below 260° C. no loss in weight occurs, was found to apply here, provided the exposure to this degree of temperature is short. If continued for many hours a slight but sensible loss is observed.

ZIRCON.

GENERAL OCCURRENCE.—Zircon is one of the most widely distributed minerals of the region, occurring as an associate of nearly all other species in veins and druses and also impregnating the granite itself. König⁴⁷ has described it as an associate of astrophyllite and as intergrown with microcline. In its usual form it is brown or nearly black in color, and has only the ground pyramid and corresponding prism, the latter quite subordinate. König identified the basal plane $01\bar{1}$, and it seems to appear in very minute form upon crystals of all modes of occurrence though on comparatively few from each place. Sometimes the zircon crystals are more than an inch in diameter, sacrificing perfection to size, as there is commonly more or less distortion of angle and unevenness of surfaces in such individuals.

ZIRCON FROM THE EUREKA TUNNEL.—Reference has already been made in describing the occurrence of cryolite to the mutual relations of the different parts of the irregular vein into which the Eureka tunnel has been driven. The part containing zircon is but small, comparatively, and is sharply defined. It evidently represents a contemporaneous formation of quartz, zircon, and microcline. Zircon crystals varying in size from less than 1^{mm} to 1^{cm} are very plentifully and uniformly scattered throughout, while small patches of reddish microcline were also included in the more abundant quartz and themselves inclosed numerous small zircons. The occurrence is noteworthy from the perfection in form and the transparency of the zircon.

The zircon crystals imbedded in quartz are sometimes perfect, but in most cases the formal development has been hindered by the surrounding mineral, producing striated or distorted faces. These crystals,

⁴⁷ G. A. König, Zeitschrift für Krystallographie, I, 423, 1877.

too, are much shattered by the jars of the blasting and the blows necessary in breaking up the larger pieces. Those smaller crystals deposited in the microcline were able to develop freely and they are now found imbedded in pure white kaolinite or a compact yellowish mica—the alteration products of the original microcline, some of which is yet visible. The nature of the surrounding material has protected these crystals from jars and also makes it possible to isolate single ones, absolutely unharmed, for examination. The color varies from a rich reddish brown to a light wine or honey yellow shade. A few minute crystals are of a deep emerald green and spots of similar color were noticed in some pinkish crystals. While a few are really gems in clearness and color, they are usually of the smallest size, and are those found in the kaolinite or mica.

The common habit of all crystals is pyramidal, the prisms being all ways subordinate when they appear. The forms determined with certainty are P , $3P$, $0P$, $3P3$, ∞P and $\infty P\infty$. The rare face $0P$ is much less frequently developed than any of the others, but it was observed distinctly on at least twenty-five crystals. Repeated measurements on different crystals of the angle $0P \wedge P$ give results varying less than $3'$ from the calculated value ($137^{\circ}50'$). Between $0P$ and P is a low pyramid appearing quite constantly with $0P$, which forms an angle of $164^{\circ}46'$ with P . This corresponds very nearly to $\frac{1}{4}P$. The angle between this form and P is replaced by a curved surface giving an almost continuous reflection, but the angle with $0P$ is distinct. $0P$ is often visible on but one termination, but it is by no means rare to find it upon both.

Chemical analysis shows this zircon to be exceedingly pure and the specific gravity of transparent crystals is 4.709 at $21^{\circ} C$.

KAOLINITE.

The chief alteration product of microcline in the Eureka vein proves to be a very pure kaolinite. Some of the large individuals are changed into a compact white foliate kaolinite in the mass of which the cleavage planes of the microcline are still indicated. In other cases a more coarsely foliate aggregate is formed, the single leaves of which are beautiful transparent crystals.

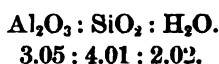
The smaller patches of microcline deposited in the zircon-bearing quartz are also changed into kaolinite or a yellow micaceous mineral whose analysis accompanies that of the kaolinite below. Sometimes small cavities in the quartz contain single projecting crystals. These are exceedingly thin, colorless, transparent, rhombic leaves, the acute angle being usually evenly truncated, producing sometimes an almost perfect hexagon. The result of many measurements under the microscope seems to indicate that the obtuse angle of the rhomb is slightly less than

120°, the best results varying from 118° 30' to 119° 30'. The thinnest leaves show distinct action on polarized light and extinguish parallel to the diagonals of the rhomb. The thicker crystals are made up of many tablets which are usually not perfectly coincident in position and sometimes form more or less perfect rosettes. The kaolinite possesses the composition XXXVII, and the mica XXXVIII, as given below. The kaolinite contained a small amount of fluorite in almost microscopic crystals, the quantity being calculated from the Ca found.

	XXXVII.				XXXVIII.
	a.	b.	Mean.		
SiO ₂	45.91	46.22	46.06	SiO ₂	52.59
Al ₂ O ₃	39.65	39.62	39.63	Al ₂ O ₃	29.72
H ₂ O	13.77		13.77	Fe ₂ O ₃	1.40
CaF ₂	0.68		0.68	CaO	0.25
				MgO	2.12
				K ₂ O	8.33
				Na ₂ O	0.59
				H ₂ O	4.59
	100.01		100.14		*99.31
(W. F. Hillebrand.)				(W. F. Hillebrand.)	

* The presence or absence of fluorine was not ascertained.

Oxygen ratio of XXXVII:



The kaolinite has nearly the theoretical composition, while the mica is probably a variety of muscovite.

PHENACITE.

FROM CRYSTAL PARK.—This mineral was first identified from two crystals found in association with topaz in Crystal Park, near Manitou. Subsequent search revealed a number of others at the same place, but as they are inferior to those originally described⁴⁸ no new data can be given of this occurrence. The crystals found are but fragments, representing in each case somewhat less than half of the complete crystal. Fig. 12 of the plate represents one crystal in about the natural size; another measures nearly 7^{cm} in longest diameter, and has the same faces developed in similar manner. In no crystal do any faces of the vertical zone appear, thus producing a flat lenticular habitus. The forms appearing have been identified as R, $-\frac{1}{2}$ R, $-R$ and $\frac{2}{3}$ P2, and although the faces are too rough to admit of exact measurements with the reflection-goniometer, the size of the faces and their simple devel-

⁴⁸Am. Jour. Sci., III, XXIV, p. 282, October, 1892.

opment render sufficiently accurate results with the hand instrument possible: The angles obtained as means of several measurements are:

	Crystal a (Fig.)	Crystal b.	Authorities.
	° /	° /	° / "
R $\wedge$ R (terminal)		116 20	116 36 (D)
R $\wedge$ R (lateral)		63 00	63 24 (S)
R $\wedge$ $\frac{1}{2}$ R (over $\frac{1}{2}$ P2)	148 30	148 50	148 18 (D)
R $\wedge$ $\frac{1}{2}$ P2	159 45	159 58	159 66 (D&S)
R $\wedge$ -R	74 30	74 40	74 42 45 (S)
$\frac{1}{2}$ R $\wedge$ $\frac{1}{2}$ R	143-144 00		144 1 26
$\frac{1}{2}$ R $\wedge$ -R		163 43	163 32 2
$\frac{1}{2}$ P2 $\wedge$ $\frac{1}{2}$ R	168 11	168 50	168 22 (S)
$\frac{1}{2}$ P2 $\wedge$ $\frac{1}{2}$ P2	166 40	156 00	156 44 (D&S)

The figures of the third column are the calculated angles given for phenacite by Dana⁴⁹ or Seligmann,⁵⁰ or else our own calculations based on the theoretical values given by them. The agreement between the angles measured on these crystals and the theoretical ones is sufficiently close to justify the signs given to the faces of the figures. In the development of the different forms R and $\frac{1}{2}$ R are always prominent, while the faces of $\frac{1}{2}$ P2 are variable. One face of $\frac{1}{2}$ P2 on crystal b is 2.5^{mm} broad, although usually each face of $\frac{1}{2}$ R is broader than both adjoining faces of $\frac{1}{2}$ P2; -R is subordinate and the faces are quite rough; $\frac{1}{2}$ P2 appears with its full complement of faces. The roughness of the faces is in part caused by striæ, which on $\frac{1}{2}$ R and $\frac{1}{2}$ P2 run parallel to the terminal edge of R replaced by those faces. On R the markings are less distinct. These striæ and partially regular depressions seem like natural etching figures, and bring out the rhombohedral symmetry of the mineral very plainly.

The crystallographical determination of these minerals as phenacite is confirmed by all the physical characteristics as far as observed and by the chemical composition. There is an imperfect cleavage parallel to ∞ P2. Both crystals are clear and colorless, resembling quartz, and the hardness is nearly or quite 8. The specific gravity of the crystal figured, though containing some impurities, is 2.967 at 23° C.

PHENACITE FROM NEAR FLOISSANT.—Another occurrence of phenacite was discovered during the summer of 1884, near Florissant, in association with the topaz crystals described later on. The crystals here are small, colorless, of lenticular form, and are deposited upon or slightly embedded in amazon stone crystals, in the same manner as the topaz, which is often present side by side with the phenacite. None seen exceed 5^{mm} in diameter, and crystals of this size in one case form an almost continuous crust upon the surface of a feldspar crystal. More commonly they are attached by an edge, although occasionally in all other positions.

⁴⁹ Dana, System of Mineralogy, 5th ed., p. 263.

⁵⁰ G. Seligmann, in Neues Jahrbuch für Mineralogie, etc., 1880, I, 129.

These small crystals, while preserving the lenticular form of those from the first locality, exhibit a development of several new faces. These can be determined with considerable certainty by a reference to the article by Seligmann, reviewing the crystallography of the species.⁵¹ All the present forms are mentioned by him as occurring with very nearly the same relative development upon the phenacite from the Ilmen Mountains, in the Urals. The zonal relations are almost sufficient to determine the new faces, although measurements were made to insure accuracy.

The new forms observed are: $-2R$, seen in a few crystals in good development; $-\frac{1}{2}R3$, which appears prominently with six nearly equal faces; $R3$, of which only three faces were found on any crystal, and which is often not developed at all; ∞R and $\infty P2$, appearing as very narrow faces, which do not produce a prismatic habit in any case and are often wanting. A narrow face sometimes seen between R and $-\frac{1}{2}R3$ is probably $\frac{1}{4}P2$.⁵²

TOPAZ.

Within the past two years topaz has been found in several places within the Pike's Peak region, and we can supplement our original notice⁵³ of the mineral quite materially.

Topaz has been found in Crystal Park, south of Manitou, in a cavity containing feldspars, smoky quartz, zircon, and phenacite; at the main amazon stone locality near Florissant, about 12 miles northwest from Pike's Peak; and, more plentifully and in better form than elsewhere, on Devil's Head Mountain (Platte Mountain), north of Pike's Peak about 30 miles.

CRYSTAL PARK.—Of the few crystals found in this locality the most perfect one measures 2.5^{cm.} parallel to the vertical axis, 3.3^{cm.} parallel to the brachy axis, and 2.8^{cm.} parallel to the macro axis. It is colorless and some parts of the crystal are very clear. The prisms ∞P and $\infty P2$ are well developed. The terminations are drusy, although many of the prominences are large enough to admit of the determination of some of the faces which bound them. The pyramid $2P$ has been recognized with certainty, while a form between $\frac{1}{2}P$ and P , which is probably $\frac{1}{4}P$, and another pyramid near $2\bar{P}4$ are also present. Measurements of sufficient accuracy for the calculation of these latter forms could not be obtained. The lateral edges of these pyramidal prominences lie in a plane corresponding to the brachydome $2\bar{P}\infty$, and although that form does not actually appear, the crystal has a domatic habit. A rough face of $4\bar{P}\infty$ is present quite distinctly. While one termination is more perfect

⁵¹G. Seligmann. "Krystallographische Notizen, I," Neues Jahrbuch für Mineralogie, etc., 1890, I, 129.

⁵²An announcement of this locality was made by W. E. Hidden, Am. Jour. Sci., March, 1885, received after this article was written.

⁵³Am. Jour. Sci., III, XXIV, p. 282, 1882.

than the other, both are alike. Not more than a dozen crystals have been found in this locality.

FLORISSANT.—The first specimen identified from Florissant is mainly noteworthy on account of the enormous size of the original crystal from which it came. This specimen is but a corner of a large crystal, the forms appearing being two faces of $\infty P2$, one of ∞P , and one each of $2P\infty$ and $4P\infty$. The fragment is about 9^{cm} ($3\frac{1}{2}$ in.) in its longest diameter, and if the other faces were developed to correspond to those here seen, the complete crystal must have been nearly or quite one foot in diameter parallel to the brachy diagonal. It is clear in parts and has a decided greenish tinge. It was supposed to be fluor spar by the original collectors, and the other pieces of the crystal are undoubtedly lost.

The specific gravity of this fragment is 3.578 at 22° C. and it has the following composition:

	XXXXX.
SiO ₂	82.15
Al ₂ O ₃	57.81
F	16.04
O for F	106.20
	6.75
(W. F. Hillebrand.)	99.45

Atomic ratio:

$$\text{Si} : \text{Al}_2 \\ 1.025 : 1.000.$$

Within a few months a further discovery of topaz has been made near Florissant. In this case the crystals were found deposited upon or partially imbedded in amazon stone, albite, or limonite (pseudomorph after siderite). The crystals seen by us are deposited upon different faces of the microcline and so seldom with any parallelism in position that any such coincidence must be considered accidental. In size the crystals vary from a length of nearly two inches to those which are almost microscopic. They are deposited singly or in groups and are attached in all positions, so that many of them are quite well terminated at both ends. The forms observed are as follows: ∞P and $\infty P2$, both polished and striated; $4P\infty$, $2P\infty$, and $\frac{1}{2}P\infty$; $0P$; $2P\infty$; P and $\frac{1}{2}P$; $\infty P\infty$.

Quite characteristic is the prominent development of the brachydomes $4P\infty$ and $2P\infty$, the former in particular, the faces of opposite terminations often meeting. $4P\infty$ is almost uniformly dull, like ground glass, while $2P\infty$ is smooth and brilliant, passing into $\frac{1}{2}P\infty$ or $0P$ by a roughened line. $\frac{1}{2}P\infty$ and $0P$ are usually rough through minute irregularities bounded by crystal planes. The base is usually very narrow through the predominance of the brachydomes, the pyramidal planes and the macrodome are quite insignificant when present at all, and $\infty P\infty$ is occasionally present as a small, smooth face. No indications of hemi-

morphism are noticeable, although the faces of opposite ends are seldom symmetrically developed.

Some of the crystals have a decided greenish tinge, although many are colorless.

TOPAZ FROM DEVIL'S HEAD MOUNTAIN.—The country embracing Devil's Head Mountain is composed chiefly of the same granite which has been described in its occurrence near Pike's Peak, and it contains similar druses of microcline, smoky quartz, and other minerals. The topaz found here is the most noteworthy crystallized species, some of the specimens found being probably the best yet discovered in the United States. The discoverer, Mr. W. B. Smith, now assistant in the Rocky Mountain division of the Survey, has given us a few notes on the manner of occurrence and associations of the topaz, which are appended to this description, p. 73.

In the American Journal of Science for December, 1883, Rev. R. T. Cross, of Denver, published a note announcing the discovery of this locality by Mr. Smith. The specimens obtained since that time are much superior to those first found, though comparatively few in number.

Specimens from Devil's Head have found their way into various mineral collections of the country, and as the most noteworthy crystals passed through our hands we are able to give some details. All are colorless or faintly wine-colored and very clear within, though marred by more or less roughened surfaces, often stained by oxide of iron which penetrates fissures. Many fragments are sufficiently clear for cutting.

Three especially fine crystals have been obtained. Of these the one with the most polished surfaces, and hence the clearest, weighs 3.5 ounces, measuring $\tilde{a}:\tilde{b}:\tilde{c}=4.4:4.9:3^{\text{mm}}$. The faces ∞P , $\infty \tilde{P}2$, $4\tilde{P}\infty$, $\frac{1}{2}\tilde{P}\infty$, $0P$, $\frac{2}{3}\tilde{P}\infty$, P , and $2P$ are quite well developed, while $\alpha P3$, $\infty \tilde{P}x$, $2\tilde{P}\infty$, and $\frac{1}{3}P$ are less prominent or not present in full quota. But one termination has definite faces.

The second crystal weighs 5.5 ounces, and measures $\tilde{a}:\tilde{b}:\tilde{c}=3.7:5.5:4.6^{\text{mm}}$. Clear with dull surfaces. One termination has large $0P$, with a very symmetrical development of the faces mentioned above and $2\tilde{P}\infty$. A second termination is formed by one large undulating face, corresponding to $\frac{2}{3}P$, with $0P$ and single faces of $4\tilde{P}\infty$ and $2P$.

A third crystal weighs $6\frac{1}{2}$ ounces and measures $\tilde{a}:\tilde{b}:\tilde{c}=4.2:5.3:4.5^{\text{mm}}$. It has rather dull surfaces but is clear within, and has a distinct wine color. One termination is quite symmetrical, showing the planes named.

A number of the smaller crystals are very clear and transparent, with beautifully polished surfaces, although it is seldom that all are smooth.

Nearly all crystals from Devil's Head, Crystal Park, and many from Florissant, have been found detached, some being badly broken. The same is true of a large portion of the crystals of the accompanying

minerals. Movements of the whole mountain mass, as in folding or faulting, have probably caused this detachment and fracture of the crystals. Particularly noticeable with the topaz, though also observed on smoky quartz, is the fact that all these old fracture planes are healed over, so to speak, and are now covered by drusy surfaces caused by little prominences which are bounded by glistening crystal faces. An examination shows that pyramidal planes of both orders are the most common, the little elevations resembling those upon 2P ∞ above described. When the fractured plane is parallel OP there are usually a great number of the pits or etching figures also previously noticed.

APPENDIX.

NOTES UPON THE OCCURRENCE OF TOPAZ AT DEVIL'S HEAD MOUNTAIN, BY W. B. SMITH.

The name "Devil's Head" was applied many years since to a jagged and precipitous mass of granite, rising to a height of 9,348 feet, in the Colorado range, some 30 miles north of Pike's Peak. This is the name by which it is still known locally, though upon Hayden's Atlas it is called "Platte Mountain."

The granite forming the mountain is similar to that near Pike's Peak, and the minerals found occur in cavities or pockets as in the latter region. No extensive pockets of amazon stone, smoky quartz, etc., have been found, but a few smaller ones contain a noteworthy association of species.

TOPAZ.—The pocket in which the topaz was found is of irregular shape, being about 50 feet long, from 2 to 15 feet wide, and averaging 4 feet in depth. Owing to the disintegration of the rock at the surface many of the crystals had been carried in the *débris* to a considerable distance down the mountain side, and were badly worn and broken.

The topaz occurs in isolated and usually loose crystals, surrounded by distorted quartz crystals, of smoky and reddish shades—frequently the exact color of the topaz—light green microcline, mamellary radiations of albite, cleavage masses and compact nodules of mica—probably muscovite, although sometimes much altered from the original substance. Also, more rarely, cassiterite, goethite, orthite?, fluorite and kaoliinite occur. Much of the topaz is reddish, though wine-yellow, milky blue, and colorless crystals were found.

All the crystals attached to the gangue were more or less decomposed, a kaolin-like substance being the result. Frequently the terminal planes and a part of the prism would be found protruding from the rock unaltered, while the remainder of the crystal, running into the

albite, would be composed of alternate layers of topaz and kaolin. More frequently, however, the kaolin, instead of being parallel to the cleavage planes, occupied curved fissures running irregularly through the topaz.

MICROCLINE.—This mineral in simple crystals was the common species in the pocket. Some were very large, measuring 18 inches across. They were usually badly fractured and fell in pieces on being removed. The base, 0 P, of each crystal has a curious appearance, owing to the angular elevations and depressions that compose the surface, looking not unlike oriental characters cut in relief.

CASSITERITE.—Twenty-five or thirty small, irregularly-shaped masses of this mineral were found embedded in massive albite or quartz. A few rude crystals were obtained, one being a little less than an inch in diameter. Only the pyramid is developed. No cassiterite was found outside of the topaz-bearing cavity.

FLUORITE.—In the adjacent region a number of interesting crystals of the chlorophane variety of fluorite were found in a small pocket of microcline and smoky quartz. The most perfect crystal is a cubo-octahedron, with every face well developed. It was found lying loose in the cavity and the surface is rough. The color is of a greenish tinge outwardly, with an included cube of dark purple.

III.—ON THE LUSTRE EXHIBITED BY SANIDINE IN CERTAIN RHYOLITES.

By WHITMAN CROSS.

The sanidines of two rhyolites in Colorado, examined by the writer, possess a remarkable lustre which is, as far as he can ascertain, unlike anything previously described by any other observer. One of these cases has already been briefly noticed in the *American Journal of Science* for February, 1884. The discovery of a second instance of this same lustre, and the results of a comparison with earlier descriptions of lustre and color in feldspar, render a fuller treatment in this place desirable.

SANIDINE IN RHYOLITE FROM CHALK MOUNTAIN.—The rhyolite containing the lustrous sanidine occurs in a massive body forming the greater part of Chalk Mountain, situated upon the continental divide at the headwaters of the Arkansas, Ten Mile, and Eagle Rivers, in central Colorado. It is of the type recently defined as nevadite by Messrs. Hague and Iddings,⁴⁴ and may be characterized as a porphyritic rock, showing large glassy sanidine and many smoky quartz crystals embedded in a grayish ground mass, which appears under the lens to be evenly granular, and is really so, with the exception of isolated glass particles revealed by the microscope. Biotite is but sparingly present. This nevadite is one of the most beautiful of rocks, owing to its abundant smoky quartz crystals and to the lustrous sanidines about to be described. Chalk Mountain lies upon the boundary between the geological maps of the Mosquito range and of the Ten-Mile mining district, which are soon to be published, with monographic reports, by the U. S. Geological Survey. In both of these works the manner of occurrence and the characteristics of the rock will be fully given.

Many crystals of sanidine in the nevadite exhibit in certain positions a delicate or brilliant satin-like lustre. If examined with the aid of a lens a faint play of very delicate colors is seen, while the crystal seems white and opaque when looking down upon the lustrous surface in such a direction that the lustre itself does not appear. The position of the lustrous plane is readily seen to be near that of the orthopinacoid, and the extent of the deviation from it is plain when a crystal twinned ac-

⁴⁴ *Am. Jour. Sci.*, III, XXVII, 461, 1884.

according to the Carlsbad law is observed. By facing the light and revolving such a crystal about its orthoaxis it is found that the lustrous planes of the two halves are not coincident, but are inclined at approximately 20° to each other, while evidently lying in or very near the orthodiagonal zone.

On examining the larger crystals a cleavage parallel to the plane of lustre is evident, and if an isolated fragment be fractured by a sharp blow upon the predominant brachypinacoid many flakes are produced, some of which are parallel to OP , while others are parallel to the lustrous surface. Those parallel to OP exhibit under the microscope a very fine striation at right angles to the trace of $\infty P \infty$, while optical action is normal. The flakes parallel to the plane of lustre are found to be made up of extremely thin plates, usually rectangular through the development of cleavages parallel to OP and $\infty P \infty$. If but a few of these plates overlies each other, delicate variegated colors appear in ordinary light. By increase in the number of plates the flake becomes dull white and opaque. The phenomena are very plainly the familiar ones produced by polarization and interference of light in traversing a series of thin plates. Transmitted light is soon wholly extinguished by a sufficient increase in the number of plates, and reflected light produces the lustre seen.

A parting parallel to this plane can be easily produced with a knife-blade in those crystals having a very bright lustre. The separation is as sharp and perfect as that parallel to any cleavage plane of the crystal. By sections parallel to $\infty P \infty$ the position of the plane with reference to the axes a and c is readily determined with approximate correctness; but the most satisfactory, and probably the most accurate, measurements were obtained in the following manner:

At one point in the mountain the nevadite, here unusually coarse-grained, was found to contain many small round or irregular druses lined by minute but perfect transparent crystals, chiefly of sanidine and quartz. The quartz crystals are for the most part simple dibexahedrons; the sanidines thin tablets, which are almost invariably Carlsbad twins, with prominent development of the clinopinacoid. Such crystals examined under the microscope, as they lie upon the predominant pinacoidal face, afford a means of determining approximately the position of the plane parallel to which the parting referred to takes place.

Fig. 13 of the plate represents one of these crystals, a normal Carlsbad twin, with a third and smaller plate, also in twin position. The faces shown in profile are ∞P , OP , $P\infty$, and $2P\infty$. From all the outlines and from basal cleavage or irregular fissures run very fine dark lines, in uniform direction for each individual of the twin, and penetrating varying distances into the crystal. This undoubtedly represents an incipient stage of that parting which, in some crystals of the rock, occasions the brilliant lustre, for these dark lines do not represent needles of

any mineral substance, but air films, upon the fissures, showing the extent to which actual parting has taken place in the direction indicated in the remainder of the crystal by the fine, clear striation. As seen from the figure, the position of the surface is that of a positive hemi-orthodome, for the cleavage plates of large crystals show the plane to be at right angles to the clinopinacoid. The mean of a number of measurements in different parts of the crystal places the inclination of the plane thus indicated to the vertical axis at $8^{\circ} 40'$. Assuming the axial ratio—

$$a:b:c = 0.653:1:0.552 \text{ and } \beta = 64.$$

as determined by Strüver⁵⁵, for free crystals of sanidine, the face corresponds closely to $\frac{1}{2} P \infty$. This would require an angle of $72^{\circ} 40'$ with the basal plane, while that measured in the crystal figured was $72^{\circ} 53'$. Of course this cannot be regarded, under the circumstances, as anything more than an approximate determination.

The lustre as thus far described is found chiefly in the sanidines of the coarser-grained modifications of the rock. Some of the crystals do not exhibit the phenomenon distinctly, and in those of the finer-grained portions of the mass it is commonly not visible at all. Yet, thin sections of such varieties do sometimes show a pale, delicate, bluish color in the sanidines, which is like that often seen in labradorite. By close examination of sections parallel to the plane of the satiny lustre it is frequently found that there are clear and transparent portions which do not exhibit the bright lustre, but if the light be properly guarded a faint bluish color is seen in these clear portions simultaneously with the satin-like lustre in the remainder. After the connection has thus been established it becomes easy to see, in most cases, that the blue color, seen only in clear and transparent crystals, appears upon the same plane which in other cases shows the satiny lustre.

SANIDINE IN RHYOLITE FROM RAGGED MOUNTAIN.—Since the appearance of the article describing the lustre of the Chalk Mountain sanidine, another and even more striking instance has been brought to the notice of the writer, through his friend Mr. R. O. Hills, of Denver, who presented him with a sanidine crystal from the rhyolite of Ragged Mountain, Gunnison County, Colorado, in which the satiny lustre is very marked. The crystal in question was several inches in length parallel to the clinocaxis, and has a square prismatic form in that direction, through the predominant and equal development of $\infty P \infty$ and $0P$. The brilliant, satiny lustre is exhibited in all its beauty when these elongated crystals are fractured transversely, and in the crystal seen the fracture is parallel to the lustrous plane itself. According to Mr. Hills, this is commonly the case, and large masses of the rock often show numerous square sections, reaching 2–3 inches in diameter, each possessing the lustre very distinctly.

⁵⁵ Cited by Tschermak, *Lehrbuch der Mineralogie*, 1883, p. 455.

From the crystal mentioned thin sections were prepared parallel to OP , $\infty P \infty$ and the plane of the lustre. That parallel to OP shows under the microscope uniform extinction $\pm$ to the edge of $\infty P \infty$. The lustrous plane is indicated in the pure and transparent portions by a very fine clear striation lying, so far as determinable, exactly at right angles to the trace of $\infty P \infty$. This striation is exceedingly delicate, and appears most distinctly when directed from the observer toward the source of light. Through a large part of the section, however, the clear striation is replaced by dark lines, easily seen to be sections of parallel planes, upon which are many dark bodies like gas cavities or empty spaces. These are zigzag in shape, but bounded chiefly by lines seemingly parallel to OP and $\infty P \infty$. The plane holding these bodies is steeply inclined to OP .

The section parallel to $\infty P \infty$ shows a clear striation where parting has not taken place, and dark lines representing the sections of planes containing air or empty cavities where the separation has begun. The situation of the lustrous plane with reference to the axes a and c is here plain. The angle susceptible of most accurate measurement is that between the basal cleavage fracture (a) and the clear striation. Repeated determinations show this angle to be between $72^\circ 30'$ and 73° . This corresponds closely to the results obtained from the crystal in the Chalk Mountain rock, and shows conclusively that the lustrous planes in the two cases may be considered identical.

The thin section parallel to the lustrous plane brings out still more distinctly a zonal structure which was visible in the crystal. The outer zone has a much more brilliant lustre than the interior, and certain parts of the latter are quite transparent. In these portions, when the satiny lustre of the outer zone is at its maximum of brightness, a delicate pale blue color is visible, like that noticed in the Chalk Mountain sanidine. Under the microscope the appearance is similar to that already described for cleavage flakes. Where the lustre is brightest the parting is apparently complete, with continuous air films between plates. Where the sanidine exhibits the blue color there is either no indication of the laminated structure, or the beginnings of the parting are represented by the same dark zigzag cavities or air pores seen in the basal section. These are now clearly seen to be bounded for the most part by lines parallel to OP and $\infty P \infty$.

Although no alteration in the ordinary sense is visible, the section is opaque where the number of plates overlying each other is great.

PREVIOUS DESCRIPTIONS OF LUSTRE IN FELDSPAR.—The bluish color sometimes seen in adularia, albite, or oligoclase and the play of colors so beautifully exhibited by labradorite have been the subjects of study on the part of various mineralogists. Sir David Brewster ascribed the phenomenon to the action of certain flat rectangular bodies observed with the microscope, and which he considered as filled by air, or,

at least, by some matter of much lower refractive power than the feldspar.

The first satisfactory investigation of this subject was, however, by E. Reusch,⁵⁶ who made (1862-'63), a careful study of the bright lustrous and chatoyant colors exhibited by various minerals.

The results of Reusch's study of the feldspars are of particular interest in connection with the foregoing, and although the original has been consulted, the writer wishes to quote the concise *résumé* given by Dana in his *System of Mineralogy*, 5th edition, p. 336: "The play of colors, especially remarkable in much labradorite, and occurring also in some adularia, albite, and oligoclase, indicates, according to Reusch, the existence of a cleavage structure of extreme delicacy transverse to the median or brachydiagonal section. In adularia the plane of this cleavage is perpendicular to this section (or that of the clino-diagonal); in labradorite it is in general more or less inclined, and differently in different specimens. The play of colors, Reusch observes, appears therefore to be that of thin plates; yet the lining of what he regards as a cleavage system appears to be of indistinguishable minuteness; and although the existence of thin plates can hardly be established by the microscope, it is proved by their effects in the play of colors, nebulous images within, and the phenomena of inflection or diffraction which result from their regular grouping." By preparing a polished surface parallel to the orthopinacoid, Reusch determined, for adularia, the inclination of the plane producing the nebulous images to the vertical axis, at $11^{\circ} 38'$, as a mean of many careful observations. The angle with the clinoaxis is given at $74^{\circ} 18'$. The corresponding measurements of the cleavage inclinations in the Chalk Mountain sanidine given above are $8^{\circ} 40'$ and $72^{\circ} 53'$. If we assume $\beta = 63^{\circ} 53'$ for adularia, as is commonly given, the latter measurement of Reusch would require the former angle to be $10^{\circ} 25'$, and as the value $11^{\circ} 38'$ was obtained from an artificially-prepared surface we may perhaps be justified in considering the measurement $74^{\circ} 18'$ the more correct, in view of the nearer agreement thus shown with the results on sanidine where the direction of the new cleavage plane is more distinctly indicated.

It seems almost unnecessary to point out any more clearly that the actual parting observed in the sanidines of these rhyolites is a beautiful natural proof of the correctness of the conclusion drawn by Reusch from his admirable investigation. The satiny lustre is caused by the fuller development of that internal lamellar structure which produces the beautiful delicate blue color in clear adularia or sanidine in the manner explained by Reusch.

Vogelsang, who made a study of the play of color in labradorite,⁵⁷ ex-

⁵⁶E. Reusch, "Ueber das Schillern gewisser Krystalle," in Pogg. Ann., CXVI, 392; CXVIII, 256; CXX, 95.

⁵⁷Cited by Naumann-Zirkel. Mineralogie, p. 158, 11th Ed., Original in "Archives Néerlandaises," Tome III, 1868.

plained the blue color as due to polarization from thin plates, the yellow and red as caused by numerous included lamellæ and microlites of mineral substances, while the green and violet shades are thought to be the result of a combination of the blue with the yellow or the red. Reusch states, as mentioned above, that the undeveloped cleavage in labradorite does not correspond in position to that in adularia, being near the brachypinacoid and variable in different specimens.

From the above it seems quite possible that the rectangular bodies thought by Brewster to be the cause of the bluish color may have been the equivalent of those seen in the sanidine, which indicate the beginning of the actual parting in the direction of the latent cleavage.

LUSTRE UPON OTHER SANIDINES.—In the Microscopical Petrography of the Fortieth Parallel (p. 83), Professor Zirkel mentions a "superb blue color" as characteristic of the small sanidines in a rhyolite from Chataya Peak, Pah Ute Mountains, Nevada. It is also visible in various rhyolites east of the point named. The cause of the color is thought unexplainable, for "no strange particles can be detected, neither needles, nor plates, nor grains, nor a dust-like powder, nor glass or fluid inclusions."

An examination of these rhyolites by the writer indicates clearly that this phenomenon is simply another instance of that which has been described. The intensity or brilliancy of the color exhibited in some of these rocks is quite striking.

CONCLUSION.—The phenomenon which has been described does not seem comparable with any hitherto recognized property of crystals. It seems incorrect to speak of it as "cleavage," for that internal structure manifested by the fine basal cleavage of this same species is accompanied by no such optical action; nor can the writer recall any such combination in any other mineral. This lamellar structure is to be considered as another of those physical characteristics of minerals, such as cleavage, fracture-figures, "*gleitflächen*," etching-figures, twinning produced by pressure, etc., which will doubtless remain unexplained until the molecular constitution of crystallized bodies is made clear.

IV.—AN UNUSUAL OCCURRENCE OF TOPAZ.

By WHITMAN CROSS.

The nevadite of Chalk Mountain, which was described in the preceding section, contains in its small drusy cavities another mineral of decided interest besides the sanidine. Accompanying the quartz and sanidine in the cavities are minute leaflets of biotite, a few ore grains, and, in a few druses only, very perfect crystals of colorless transparent topaz. Usually but a single crystal of topaz is present in one of the druses, and that is larger and more perfect in development than any other. The topaz is attached directly to the walls of the cavity and often bears small tablets of sanidine upon it. The crystals which can be recognized as topaz vary from 0.5^{mm} to 3^{mm} in length, but it seems quite probable that there are some smaller ones indistinguishable from quartz.

The determination as topaz rests upon the crystalline form which is very distinct and is that of common topaz. One crystal measuring 3^{mm} in length and 1^{mm} in thickness was removed from the rock and its angles measured with a Fuess reflection goniometer. This crystal presents ∞P , $\infty \bar{P}2$, and $2\bar{P} \infty$ as the dominant forms; $0P$ is a narrow face and $4\bar{P} \infty$, $2\bar{P} \infty$, $2P$, and P are minute, but very distinct. The angles measured are as follows:

	°	'
$\infty P \wedge \infty P$	124	16
$\infty \bar{P}2$ over $\infty \bar{P} \infty$	93	7
$0P \wedge 2\bar{P} \infty$	136	30
$0P \wedge P$	134	11
$0P \wedge 2P$	115	55

$2\bar{P} \infty$ appears as a very narrow face in the zone of $2P$ to $2P$. This is the usual habit, with the occasional addition of $\infty \bar{P} \infty$ and a more prominent development of $0P$. This crystal is also imperfectly terminated at the attached end, showing $2\bar{P} \infty$ most prominently, with $4\bar{P} \infty$ and $2P$ also recognizable, and there are no signs of hemimorphism.

In some druses all crystals are thinly coated by a black incrustation which seems to be pyrolusite.

So far as I can ascertain, all previously known and described occur-

rences of topaz are in granite, gneiss, or some other member of the series of metamorphic or crystalline schists. In the present case topaz is found in an eruptive rock, probably of early tertiary age, while the appearance of the associated minerals certainly suggests that they may all be sublimation products, though it is not capable of direct proof. The sanidine crystals from the druses, examined microscopically, contain gas inclusions, while neither fluid nor glass inclusions were seen.

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V.—ASSOCIATED RARE MINERALS FROM UTAH.

BY W. F. HILLEBRAND.

In the American Eagle mine, Tintic mining district, Utah, occur, in intimate association, several minerals, the majority of which, it is believed, are new to the American continent. All the specimens examined were obtained from an ore-heap at the works of the Boston and Colorado Smelting Company, near Denver, where they were first observed and their probable identity established by Mr. Richard Pearce, metallurgist to the above company. More detailed examinations were made in the laboratory of the Survey at Denver, as opportunity offered, in compliance with a desire expressed by Mr. Pearce.

OLIVENITE.

Recognizable by its dark olive-green and wood-brown color, and by its crystal form, is olivenite, occurring in a mixture of various brown and yellow oxygen salts of iron, copper and calcium. The only planes observed, according to Mr. Whitman Cross, belong to the prism and brachydome. While fine crystals are not of infrequent occurrence, the major part of the mineral appears in that characteristic brown, compact, fibrous state to which it owes its old name of wood-copper. The amount of crystallized material available sufficiently pure for a satisfactory analysis was very limited on account of the firm adherence of small green hemispheres of conicalcite on many of the crystals. Analysis gave the following results:

	XL.
CuO	55.40
As ₂ O ₅	40.05
P ₂ O ₅	0.06
H ₂ O	3.39
Fe ₂ O ₃	0.25
CaO	0.16
ZnO	Trace.
Quartz	0.40
	99.71

The ferric oxide of the analysis was derived from a little adhering hydrated cupri-ferric arseniate and the calcium and zinc oxides from attached conicalcite.* The oxygen ratio for CuO : As₂O₅ (P₂O₅) : H₂O is

4.00 : 5.00 : 1.08, instead of 4 : 5 : 1 required by the formula $\text{Cu}_3\text{As}_2\text{O}_7 + \text{H}_2\text{CuO}_2$.

CONICALCITE.

Covering the surface of often large pieces of more or less soft and friable mixed arseniates, sometimes uniting to form a complete coating, are innumerable beautiful emerald-green semi-translucent globules, averaging three-fourths of a millimeter in diameter and showing distinct radiate structure when broken. Notwithstanding the considerable amount of material from which to select, the obtaining of perfectly pure material in sufficient quantity for analysis was impossible without devoting several days to the work, in consequence of the firm adherence of gangue to the flattened base of the globules and of the fact that the nucleus of each globule usually consisted of some of the same soft gangue matter. The material analyzed was so small in quantity, therefore, that the analytical results can lay no claim to the highest degree of accuracy, especially as all estimations had to be made upon the same portion. No specific gravity determination was attempted for this reason, and also because there were no means of determining the corrections to be made for small amounts of impurities other than quartz.

	XLI.	Conichalcite from Spain.
CuO	28.68	31.76
CaO	19.79	21.36
MgO	0.54	.....
ZnO	2.88	.....
Ag	0.30	.....
As ₂ O ₅	39.94	30.68
Fe ₂ O ₃	0.14	8.81
V ₂ O ₅ .....	.....	1.78
H ₂ O	5.52	5.61
Fe ₂ O ₃	0.86	.....
CO ₂	*0.97	.....
Quartz	0.90	.....
	100.00	100.00

* By difference.

The ferric oxide was derived from attached gangue. The carbon dioxide was probably combined with lime, since a temperature was required for its expulsion higher than that at which all the water escaped, the latter having been estimated by direct weight. Part of the water seemed to escape at a much lower temperature than the remainder. The silver is not a constituent of the gangue, since none could be found in the latter underlying the green coating. It is not present as chloride, for nitric acid readily takes it all into solution; nor could any native silver or sulphide be detected. The only conclusion to be drawn is that it exists in the mineral in an oxidized state, presumably as silver arseniate.

In appearance and composition this mineral resembles no other than conichalcite, found hitherto only in Andalusia, Spain, and represented by a single analysis in Dana's System of Mineralogy, p. 563 (quoted above

for the sake of comparison). It will be noticed that vanadium is wanting (it was specially looked for) in the mineral from Utah, and phosphorus nearly so; while zinc, which was not a constituent of the Spanish mineral, here replaces apparently some copper.

Allowing for the CO_2 its equivalent of CaO , the oxygen ratio is as follows:

$$\begin{array}{lcl} \text{RO} : \text{As}_2\text{O}_5 (\text{P}_2\text{O}_5) : \text{H}_2\text{O}. \\ 1.00 : 1.18 & : 0.41. & \text{or} \\ 4.00 : 4.72 & : 1.64. \end{array}$$

instead of 4 : 5 : 1.5 required by the supposed formula $(\text{Cu}, \text{Ca})_3 \text{As}_2\text{O}_8 + \text{H}_2\text{CuO}_2 + \frac{1}{2}\text{H}_2\text{O}$.

Heated in any manner before the blow-pipe most violent decrepitation ensues, the entire fragment flying into fine powder. In a closed tube, after decrepitation has ceased, the particles by gentle tapping may be made to collect at the bottom as a brown-black spongy mass of great volume. This collected on a loop of platinum wire fuses before the blow-pipe, at first with a pale bluish coloration of the flame. This behavior accords in a measure with that mentioned in Dana's System of Mineralogy (*loc. cit.*).

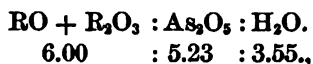
CHENEVIXITE.

Thickly scattered in irregular patches throughout some portions of such ore as occurs in hard lumps, giving to a broken surface a mottled appearance, is a compact greenish opaque body, with little or no lustre, which corresponds in composition very well with chenevixite from Cornwall, as represented by one of the two analyses in Dana's System of Mineralogy, p. 583. The hardness, however, is lower, being 3.5 instead of 4.5, as there given. The color is an olive-green, sometimes shading away into a greenish yellow after exposure. The fracture is subconchoidal.

	XLII.			Chenevixite from Cornwall.
	a.	b.	Mean.	
CuO ...	26.41	26.21	26.31	31.70
CaO ...	0.44	.....	0.44	0.34
MgO ...	0.16	.....	0.16	.....
Fe ₂ O ₃ ...	27.37	.....	27.37	25.10
Al ₂ O ₃ ...	0.66	.....	0.66	.....
As ₂ O ₅ ...	35.08	35.20	35.14	32.20
P ₂ O ₅ ...	.....	.....	.....	2.30
H ₂ O ...	9.41	9.25	9.33	8.06
Quartz	0.40	.....	0.40	.....
	99.93	.....	99.81	100.30

The analysis was made upon air-dried powder, since the latter loses about 0.75 per cent. of water even over sulphuric acid, which loss be-

comes slightly greater at 100° C., and continually increases as the temperature rises. The oxygen ratio is—



while that of the above-quoted analysis of the Cornwall mineral is 6:5.35:3.30 instead of 6:5:3, as assumed most probable. The material now analyzed cannot with any certainty be regarded as pure, hence the deviation from this theoretical ratio is not of great importance.

Before the blow-pipe the mineral from Utah differs from that from Cornwall, in that it does not usually decrepitate, while in other respects the behavior is identical; it fuses readily, gives off arsenical fumes, and leaves a black magnetic scoria.

Both chenevixite and conichalcite appear to be generally regarded as doubtful species, for their names do not figure at all in some of the best mineralogical works, but it can hardly be questioned now that they represent definite species whose precise nature, however, is yet a matter for further investigation to reveal.

A HYDROUS CUPRI-CALCIUM ARSENIATE.

In rare instances, fine silky white needles have been observed, chiefly on conichalcite, but in such small quantity that the only data as to their composition are the following determinations made by Mr. Pearce on less than a centigram of material:

CuO	31.5
As ₂ O ₅	33.6
CuO and H ₂ O*	29.9
	100.0

* By difference.

The copper estimation was a failure, but the percentage of CuO was judged to be fully 20 per cent. The composition would then seem to be near that of conichalcite with the proportions of CuO and CaO reversed, but in view of the wide limits to be allowed for possible error in the analysis, further comment is useless.

JAROSITE.

Jarosite in fine transparent brown crystals was observed by Mr. Pearce on a few specimens of ore. The identification rests upon partial chemical analysis, and more fully upon angle measurements by Mr. Whitman Cross.

THE MASSIVE ORE.

With jarosite is completed the list of probably distinct species, as far as observed, with the exception of one or two others present in too small quantity for even qualitative identification. There are, however, cer-

tain characteristic components of the ore which seemed to merit examination.

A portion of the ore is a brown substance, showing nodular forms and a granular surface when broken and of considerable hardness owing to disseminated quartz. Analysis furnished the following results:

	XLIII.
Fe ₂ O ₃	44.22
Al ₂ O ₃	0.48
CuO	1.30
CaO	1.33
MgO	0.10
K ₂ O	1.72
Na ₂ O	0.46
As ₂ O ₃	20.01
S	6.66
H ₂ O	11.02
Quartz	12.00
	99.30

These figures probably represent a mixture of a hydrated ferric-alkali sulphate (perhaps jarosite), and one or more hydrated arseniates.

In places it passes gradually into a brilliant black substance, closely resembling jet, and possessing conchoidal fracture, difficult to extract even in very small quantity, but having, according to Mr. Pearce, the following composition:

Fe ₂ O ₃	41.47
CuO	4.88
CaO	7.27
As ₂ O ₃	27.65
Ign	18.49
	99.76

It was subsequently ascertained that the loss on ignition represents SO₃ as well as H₂O, hence it is useless to attempt the construction of a formula.

Filling interstices between the nodular forms of the brown mixture above described and occurring as an irregular coating on much of the ore, there is a soft powder of a bright straw color of which the average composition is as follows:

	XLIV.
Fe ₂ O ₃	37.84
PbO	13.74
CuO	2.33
K ₂ O }	*3.93
Na ₂ O }	
As ₂ O ₃	12.22
P ₂ O ₅	0.40
SO ₃	16.85
H ₂ O	9.39
Quartz	8.30
	100.00

*By difference.

The resemblance to certain alteration products of galena and pyrite found in several of the Leadville mines is striking, and, like some of these, it seems to be a mixture of lead sulphate, jarosite, and hydrated ferric arseniate.

All of the above-described minerals and mixtures, with exception of crystallized jarosite, may sometimes be observed on one and the same piece of ore. It is not improbable that further investigation at the mine itself might bring to light still other minerals belonging to the group of hydrous arseniates.

In this connection it may be mentioned that Mr. Pearce has identified pseudomalachite occurring with hübnerite (see p. 96) from near Phillipsburg, Montana Territory. According to Mr. Pearce's analysis it contains CuO 62.56, P_2O_5 20.10, H_2O 17.34 (by difference).

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VI.—MISCELLANEOUS MINERAL NOTES.

By W. F. HILLEBRAND.

LÖLLINGITE.

OCCURRENCE.—The cobaltiferous and nickeliferous variety of löllingite which is to be described occurs at the head of Brush Creek, Gunnison County, Colorado. It has been found in the Luona mine at the western base of Teocalli Mountain, and in the American Eagle and Horace Porter mines on White Rock Mountain. The peculiar ore bodies of which the löllingite forms a part are irregular masses, the relations of which are not yet understood. The investigations of the United States Geological Survey, now in progress in Gunnison County, include the area of Brush Creek, and these interesting bodies will be carefully studied.

At the Luona mine, according to Mr. J. G. Ridgley, of Denver, the löllingite is associated with native silver, proustite, argentite, pyrrhgyrite, chalcopyrite, galena, siderite, barite, and calcite, the last three composing the gangue. Much of it is decomposed, forming secondary oxidized products, most conspicuous among which is erythrite. At the other localities smaltite is a common associate. The smaltite analyzed by Dr. W. M. Iles (*Am. Jour. of Sci.*, III, XXIII, 380, 1882) was probably from one of the mines on White Rock Mountain.

DESCRIPTION.—The löllingite occurs in compact, massive form, and also embedded in barite or siderite, and presents a very striking appearance on fresh or newly fractured surfaces. There are seen embedded in the siderite and barite gangue, steely white forms, about one-eighth of an inch in diameter, of pronounced radiate structure, the longer radii protruding from the mass and giving the whole a beautiful stellate appearance. The star forms occur sometimes single, but more frequently joined together in greater or less number without losing in any marked degree the peculiar character of the individual. In some specimens the appearance approaches that of a dense, homogeneous mass, several inches in diameter, but even in the densest portions the radiate structure is generally distinctly discernible.

In order to discover, if possible, a clue to the crystallographic structure, and also to obtain material for analysis, specimens were treated with hydrochloric acid without previous crushing, whereby the siderite

and the arseniates of iron, cobalt, and nickel were entirely dissolved. The löllingite remained quite black on all parts where the gangue had been eaten away, but surfaces of previous fracture retained their white color. The star like forms were then seen to be composed of a considerable number of long flattened ellipsoids, interpenetrating at a common centre in every direction. When one of these clusters was broken through, the star form appeared on the surface of fracture. The aggregates were joined together loosely, now that the cementing material had been removed, though frequently in large clusters of many hundreds of all sizes, from those visible only with the aid of a microscope to others an eighth of an inch or more in diameter.

A microscopical study of the finer part of the material liberated from its imprisonment in the gangue, and broken off from the larger pieces during the treatment with acid and subsequent washing, furnished the solution to the question as to what was the crystallographic form of the flattened ellipsoids composing the aggregates, and the law of the twinning. The fundamental form is that of löllingite, showing only the prism and macrodome, as in Fig. 14.⁵⁸ Frequently these two forms are equally developed, producing a resemblance to a low pyramid of the tetragonal system. Very few even of the most minute crystals are perfect in form, and possessed of sufficiently smooth surfaces to allow of even approximate measurement under the microscope. Repeated attempts were made to get these in proper position under the instrument, but in only one case with comparative success, owing to their microscopic size. The angle of the prism was then found to be very nearly 122° , that given for löllingite being $122^{\circ} 26'$.

Parallel to the combination edge of the prism and macrodome there is almost always on the prism a striation (more coarsely marked the larger the crystal), caused by the alternate reproduction of the prismatic and domatic faces. Approaching the combination edge the reproduced dome face becomes relatively larger than that of the prism, the consequence of which is a gradual rounding of the corners and a contraction, and eventual disappearance of a distinct terminal dome, the result being, as represented in Fig. 15, an elipsoidal form with a slight ridge through the center representing a prism edge. Frequently the corners of a crystal, occupying the position of Fig. 14, appear as if modified by a brachydome, but no such form has been observed, the replacement being a straight serrated edge, caused by the same alternation of faces as in the case of rounded corners. Even where the macrodome is well developed it generally shows a continuation in some degree of the prismatic striation parallel to the same combination edge.

The first step toward the complex twin structure is the formation of

⁵⁸ All the accompanying figures, with the exception of Fig. 14, were drawn by the aid of a camera lucida, and therefore make no pretensions to crystallographic accuracy. Fig. 17 is magnified about 15 diameters, the others from 40 to 150 diameters.

a single twin, or, rather, trilling, by interpenetration of three single crystals having the basal section in common, and a face of the prism as composition face (Fig. 16). A basal section shows a six-rayed star, with angles of very nearly 60° , by microscopical measurement, between the axes of the rays. In the microscopic trillings one individual frequently predominates greatly in size over the other two, these appearing often as thin leaves, projecting but a short way out of the larger crystal. These trillings are finally found again interpenetrating, not according to any recognizable law, but seemingly in every direction, and in indefinite numbers, forming thus the complex aggregates first spoken of. All these stages of changes in form may be observed with great ease under the microscope, the very smallest crystals alone showing crystallographic faces well defined. As the crystals, single or twin, increase in size, the faces gradually grow more and more indistinct, and finally disappear entirely in consequence of increasing striation.

Notwithstanding repeated attempts, the basal cleavage mentioned in text-books as characteristic of löllingite could rarely be produced, and no cleavage in any other direction except in the case of the trillings. Here an individual frequently broke off at the line of union of the three; that is, in a plane parallel to the brachypinacoid.

Aside from the forms distinctly recognizable as löllingite are, however, others belonging apparently to two different minerals. The first of these became visible on dissolving the gangue, when there came to the surface of the acid and the water used for washing out the latter a great number of minute but brilliant metallic particles, which resolved themselves, under the loupe, but still better under the microscope, into thin leaves or blades, of which Fig. 17 represents one of the more perfect examples. Its forms appear to consist of two pinacoids of the rhombic system, one very broad, the other very narrow, and a terminal dome having an angle of almost exactly 90° by microscopical measurement. The faces are most brilliantly reflecting. Distinct cleavage was not observable. The second mineral, which is almost always microscopic in size, is represented in Figs. 18, 19, and 20. The prominent form is that of a lengthened prism with an angle of very nearly if not quite 90° . Repeated measurements gave values fluctuating between 88° and 92° as the extremes. It is terminated at right angles by a basal plane, the four corners of which are frequently replaced by faces which may be those of a pyramid or two domes, according as the habit is pinacoidal or prismatic. The cleavage is parallel to the base. Single crystals are rare, two or more being generally seen interpenetrating, as in Figs. 18 and 19, generally at an angle of 90° , or united, as in Fig. 20. In the latter figure only the outlines, not the faces, of the different horizontal individuals are shown; nor do the numerous vertical attachments present appear. Occasional instances of three prisms crossing at right angles like the axes of a rectangular system were observed, and also a single instance of the form represented in Fig. 21, where

each of the arms showed a domatic face. The most striking feature of all but the last of these different forms is the invariable widening at the point of union or intersection, as shown in the figures.

CHEMICAL COMPOSITION.—Even an approximate separation of the last two minerals described, from each other and from the smallest löllingite crystals, was impossible, hence no conclusion could be reached as to their quantitative composition. Qualitative tests proved them both to be arseniates of cobalt, the square prismatic forms containing also iron and nickel. An incomplete quantitative test upon a mixture of these three minerals showed a much higher percentage of cobalt and nickel than the analysis of the pure löllingite.

Before the blow-pipe the löllingite furnished the reactions mentioned in the text-books, the residue after treatment with charcoal being infusible, strongly magnetic, and, furthermore, giving the characteristic reaction for cobalt with fluxes; soluble in nitric acid, giving a pink solution.

Of the analyses given below, XLV was made upon clusters of löllingite trillings, free, so far as could be determined by the loupe, from attached or penetrating blades or prisms of the other two minerals described. As a check a small quantity* of the single crystals and trillings was picked out with the utmost care under the microscope and subjected to partial analysis (XLVI), no trace of foreign adherent matter being visible. The specific gravity of the material used for the first analysis was 7.335 at $14\frac{1}{2}^{\circ}$ C. Correcting for one half per cent. of siliceous gangue of assumed specific gravity 2.65, the true specific gravity of the mineral becomes 7.400.

	XLV	XLVI
As.....	71.18	.....
S.....	0.56	.....
Bi.....	0.08	.....
Cu.....	0.39	.....
Fe.....	22.96	22.69
Co.....	4.87	4.20
Ni.....	0.21	0.19
	99.75	

The first of these analyses leads closely to the formula $\text{Fe}(\text{Co}, \text{Ni})\text{As}(\text{S})_2$, while XLVI shows beyond a doubt that both cobalt and nickel are constituents of the löllingite and not derived from attached crystals of either of the other minerals. The presence of cobalt recalls the glaucopyrite of Sandberger, though the antimony found in that mineral is here wanting. The peculiar comb-like excrescences described by him, indicating rhombic twinning by interpenetration, may be analogous in some degree to the twinned structure of the present mineral.

Some varieties of rhombic CoAs_2 , all of which, according to Leroy W. McCay,⁵⁹ should be united under the name safflorite, present features

⁵⁹Inaugural Dissertation, Freiberg, 1883.

remarkably like some of those herein described, notably as regards the tendency to form twins of interpenetration; and from the presence of cobalt it might be suspected that this mineral was rather to be considered as safflorite than löllingite. Its exceedingly high percentage of iron and high specific gravity, both greater than that of any safflorite yet examined, are not unimportant objections to this conclusion.

In the description of this mineral in the *American Journal of Science*, Vol XXVII, p. 354, through a misapprehension not to be explained in a few words, Sandberger is wrongly quoted as authority for the statement that the brachydome is characteristic of rhombic Co As_2 . Attention was called to this error by Mr. Leroy W. McCay, who is inclined to consider the above-described mineral as safflorite. While acknowledging that through the elimination of the statement referred to, the main point there brought forward in favor of identity with löllingite was taken away, the evidence is by no means conclusive that the mineral should be classed with safflorite. Further examination, especially of a crystallographical nature, on both löllingite and safflorite, are necessary in order to settle this question. The mineral having been already described as löllingite, this name is here retained.

ZINCKENITE.

In the Brobdignag mine, Red Mountain, San Juan County, Colorado, occurs a massive gray mineral showing greasy metallic lustre, without apparent crystalline structure, but to all appearances of complete homogeneity; of specific gravity 5.21 at 18°C . and hardness 3–3.5, which upon analysis was found to be an arseniferous zinckenite, this being, it is believed, the first observed occurrence of the mineral in the United States. Besides the usual blow-pipe reactions for zinckenite, including violent decrepitation, there appear those for arsenic, preceded in the closed tube by a light sublimate of sulphur. The results of analysis are:

	XLVII.	
	a.	b.
Sb	35.00	
As	5.64	5.59
Pb	32.77	32.79
Cu	1.20	
Ag	0.23	
Fe	0.02	
CaO	0.31	
K ₂ O }	0.45	
Na ₂ O }		
S	22.50	22.50
Gangue	0.59	
	98.71	

The atomic ratio is, for

$$(\text{PbCu}_2\text{Ag}_2) : (\text{Sb}_2\text{As}_2) : \text{S} \\ 1.00 : 1.09 : 4.11. \\ (311)$$

While this is close enough to the theoretical ratio 1:1:4 to establish the probable formula PbS, Sb_2S_3 , the result was not such as the care expended on the analysis warranted, supposing that no impurities were present. Calculation shows that while the antimony and arsenic taken together are in excess of the amount required for lead, copper, and silver, the sulphur falls short by half of one per cent. The actual deficit in the latter amounts, however, to about one per cent., for it was found that about half of one per cent. existed in the free state and could be extracted by carbon-disulphide. The only explanation of these contradictory circumstances was to be sought in the presence of oxygen salts, which would at the same time account for the difference between the sum total of the analysis and 100.

Ammonium acetate failed to extract any lead sulphate, but nevertheless pure water extracted a not inconsiderable quantity of soluble matter, even when the digestion was carried on in an atmosphere of carbonic acid. The filtrate showed neither acid nor alkaline reaction toward litmus paper. Silver nitrate produced no precipitate whatever, thus showing the absence of soluble chlorides or sulphides; but hydrogen sulphide threw down a copious orange-colored precipitate of antimony trisulphide and the corresponding arsenic compound, entirely free from lead. Barium chloride produced a slight precipitate of barium sulphate. The antimony consequently existed in solution in an oxidized state—that of trioxide—as shown by evaporating some of the original solution with hydrochloric acid and adding potassium iodide. The manner of combination was not ascertained, but from the presence of alkalies this seems pretty certainly indicated. The salts, whatever they may be, are not very readily soluble, for six digestions with warm water in an atmosphere of carbonic acid were insufficient to complete the extraction. The sulphur trioxide found was probably combined with lime.

These experiments show that a large part of the apparent loss in the analysis is to be made up by oxygen, which, by requiring a considerable proportion of antimony, arsenic, and sulphur for combination, brings the ratio of the elements actually constituting the zinckenite very near that required by theory. They also show that the specific gravity given above, even were it corrected for quartz, is too low. Suitable corrections for quartz, free sulphur, and soluble salts would undoubtedly increase the specific gravity to the figure given in textbooks, *i. e.*, 5.3–5.35.

The above method of examination and its results have been dwelt upon somewhat in detail, because they show so clearly that apparent homogeneity in the case of non-crystallized metallic sulphides is no criterion of their purity, and also because thereby is indicated a possible way of reconciling with some definite formula the results of many analyses, especially of massive uncrystallized metallic sulphides, like the one here de-

scribed, whose position in a system of classification might otherwise be impossible of precise determination. (See also Gütermanite, p. 106.)

COSALITE.

In the collection of the Colorado Scientific Society are a few specimens of a mineral from the Comstock mine, near Parrott City, La Plata County, Colorado, presented by Mr. R. C. Hills, according to whom it occurs in a quartz vein associated with pyrite, sphalerite, a telluride of unknown composition, though probably sylvanite, and native gold. In the specimens examined it appears in irregular masses of small size, rarely an inch in length, and generally much smaller, without cleavage or recognizable crystalline structure except for an occasional faint indication of fibrous texture on fractured surface. The fracture is irregular; color, grayish white, but pale yellow on exposed surfaces; hardness, about 3.5; specific gravity undetermined.

The outer zone of the small bodies spoken of is found on close examination to be a mixture of two or more minerals, among which minute grains of pyrite were alone recognizable. Sufficient material was, however, obtained for analysis, free from all impurity, except a little pyrite and 1.29 per cent. of insoluble gangue. This afforded the following reactions: In closed tube, sublimate of sulphur; in open tube, formation of sulphur dioxide; on charcoal, fusible, giving reactions for lead, bismuth, silver, and copper; soluble in chlorhydric and nitric acids, in the former with precipitation of silver chloride.

The analysis, after deduction of the gangue, gave these results:

	XLVIII.*
Bi	62.98
Ag	8.48
Cu	7.50
Pb	22.49
Fe	0.70
Zn	Trace.
S	17.11
	99.16

* The following atomic weights are used: Bi, 208, Ag, 108, Cu, 63.4, Pb, 207, Fe, 56, S, 32.

Allowing for the iron and a proportionate amount of sulphur as pyrite, the atomic ratio deduced from the above is:

$$\begin{aligned} R &: \text{Bi}_2 : \text{S} \\ 2.00 &: 1.00 : 4.94 \end{aligned}$$

showing the general formula for the mineral to be $2\text{RS} + \text{Bi}_2\text{S}_3$, wherein R represents Pb and the double atoms Ag_2 and Cu_2 . The ratio of $\text{Ag}_2 + \text{Cu}_2 : \text{Pb}$ is 1 : 1.11.

Although copper was absent, and but 2 per cent. of silver present in the mineral originally described by Genth as cosalite, it does not appear

advisable, in the absence of any data as to the crystallographic form, to consider this a distinct species, but to class it, as has been done with bjelkite, under cosalite.

HÜBNERITE.

In the collection of the Colorado Scientific Society are specimens of hübnerite from the Royal Albert vein, Uncompahgre district, Ouray County, Colorado.

The mineral occurs in long flattened crystals vertically striated, imbedded in quartz, but none sufficiently well formed for measurement could be extracted; in fact, definite faces are rarely visible, though two prisms and the orthopinacoid have been observed. The lustre is sub-vitreous to resinous, and the color brownish black to pale yellow in very thin crystals. In transmitted light the color is ruby red to yellow, slightly tinged with green when the thickness is not too great. Extinction takes place parallel to the vertical axis in a plate parallel to the orthopinacoid, and at an angle of 19° to 20° to the same axis in a cleavage section parallel to the clinopinacoid, as observed by Des Cloizeaux for wolframite. In the plates parallel to the orthopinacoid a tendency to cleave at right angles to the clinopinacoid and also at angles approximating 61° and 68° to the same face was observed. The specific gravity at 24° C. is 7.177, and the composition as follows:

	XLIX.
SiO ₂	0.62
Nb ₂ O ₅ (?)	0.05
WO ₃	75.58
MnO	23.40
FeO	0.24
Cs ₂ O	0.13
	100.02

Which agrees very closely with that required by theory for the formula MnWO_4 .

This mineral is also found in a mine near Phillipsburg, Montana, according to Mr. Richard Pearce. The specimens in the collection of the Colorado Scientific Society show large flattened crystals of imperfect form in quartz. Mr. A. H. Low, chemist at the Boston and Colorado Smelting Works, has analyzed the mineral approximately and found:

WO ₃	74.82
MnO	25.00
FeO	0.06
	99.88

Other localities of occurrence in Colorado are Jamestown, in Boulder County, and near Silverton, in San Juan County.

BINDHEIMITE.

A specimen of bindheimite from a claim near the Bertrand mine, Secret Cañon, Nevada, came into possession of the Colorado Scientific Society, and was analyzed in the laboratory of the Survey. The specimen was compact and devoid of crystal form, except for a few minute crystals impossible of identification. The color, in general a yellowish green, was in places lemon yellow. The specific gravity at 19° C. was 5.01, after allowing for 4.59 per cent. of quartz of 2.65 specific gravity, and 20.33 per cent. of cerussite of specific gravity 6.5. The following are the results of analysis :

	L.		
	a.	b.	Mean.
PbO	49.68	49.82	49.50
CuO	0.58	0.59	0.58
ZnO	0.17	0.19	0.18
CaO	0.66	.....	0.66
MgO	0.08	.....	0.08
K ₂ O	0.14	.....	0.14
Na ₂ O	0.21	.....	0.21
H ₂ O	5.86	5.87	5.86
Sb ₂ O ₃	35.18	35.21	35.20
Fe ₂ O ₃	0.09	.....	0.09
Ag	0.29	.....	0.29
CO ₂	3.35	3.36	3.35
Quartz	4.59	.....	4.59
	100.83		100.68

Of the water 1.95 per cent. escaped over sulphuric acid, and a further 0.70 per cent. at 100° C. The oxygen ratio derived from the above, excluding PbCO₃, Ag, and Fe₂O₃, is:



$$3.14: 10.00: 5.92$$

If that water which escapes over sulphuric acid be considered true hygroscopic water, the ratio becomes 3.14:10.00:3.98. The first of these ratios corresponds to the formula 3 PbO, 2 Sb₂O₃, 6 H₂O, while the second is represented by 3 PbO, 2 Sb₂O₃, 4 H₂O.

KAOLINITE.

In the American Journal of Science, Vol. XXVII, 1884, p. 472, Mr. R. C. Hills gave a short description of the material whose chemical composition is discussed below. The mineral appears as a white or straw-colored powder, composed of minute scales, and occurs in certain vugs or cavities in a quartz vein material, inclosed in a large mass of eruptive rock, of which it is an alteration product. Barite, galena, and occasionally other ore minerals are associated with the kaolinite. The National Belle mine, on Red Mountain, near Silverton, San Juan County, Colorado, is the original and principal locality for this mineral.

Under the microscope the powder resolves into a multitude of most perfect transparent crystals of hexagonal form, but evidently of the rhombic system, as shown by the optical action. They present a predominant basal plane, but also very distinctly a rhombic pyramid and a brachydome of very similar development, thus maintaining the resemblance to a hexagonal form. Figures illustrating these crystals accompanied Mr. Hill's description.

CHEMICAL COMPOSITION.—The material examined contained a number of black grains as an impurity, and was of a very faint straw-yellow color, from a thin coating of limonite. The latter was mostly removed by hydrochloric acid and the former by stirring up with water in a beaker, allowing the glass to stand for a moment and then pouring off what had not yet settled. The residue was again treated in a similar manner. From the decanted portion a very pure product was obtained, of brilliant whiteness.

The fine flakes, when suspended in quantity in water, impart to the latter a most beautiful satiny appearance.

At $18\frac{1}{2}^{\circ}$ C. the specific gravity of the purified substance is 2.611. Before the blow-pipe intumescence takes place, but no fusion whatever. Strong boiling hydrochloric and sulphuric acids exercise little solvent action. The following are the results of analysis:

	LL
SiO ₂	46.35
Al ₂ O ₃	39.59
Fe ₂ O ₃	0.11
H ₂ O	13.93
F	*0.15
	100.13
Less O for F	.06
	100.07

*As mean of 0.17, 0.14, and 0.14.

The Fe₂O₃ comes undoubtedly from limonite which had not been entirely removed by hydrochloric acid.

None of the water escapes at a temperature of 330° C.; it is therefore probably all basic water. The text-books mention half the water of kaolinite as probably basic. If this is true, a marked distinction, aside from that occasioned by the presence of fluorine, exists between this mineral and kaolinite. Frenzel has described a variety of kaolin (myelin),⁶⁰ which loses none of its water until a very high temperature is reached.

This point should be carefully observed in future examinations of similar minerals, for upon the confirmation of such a difference as that mentioned, coupled, perhaps, with the presence of fluorine, there would

⁶⁰Naumann-Zirkel, Mineralogie, 11th ed., p. 676.

be necessitated the separation of such minerals as the present one and myelin from kaolinite.

A CHROMIFEROUS PSEUDOMORPH.

From the Rochelle mine, on Running Water River, Wyoming Territory, there was obtained a single fragment of a dark green mineral, apparently a pseudomorph. Although crystal planes were visible, as well as more than one direction of cleavage, the identity of the original mineral could not be ascertained, partly owing to the cutting of artificial faces. In one direction, parallel to one of pronounced cleavage, a distinct lamination was observable. Edges and thin flakes were translucent. The lustre was greasy, and the color of the powder apple-green. Specific gravity at $12\frac{1}{2}^{\circ}$ C., 2.831. Hardness about 3. Analysis gave:

	LII.	
SiO ₂	45.54	45.24
Al ₂ O ₃	37.15	} 88.07
Cr ₂ O ₃	0.79	
MgO	0.88	0.84
K ₂ O	10.70	
Na ₂ O	0.90	
H ₂ O	4.80	
	100.26	

It is evident from the analysis that the product of alteration is allied to muscovite. With substitution of Fe₂O₃ for Cr₂O₃, the composition agrees almost exactly with that of the pseudomorph liebenerite.

NATIVE LEAD.

W. P. Blake describes in the American Journal of Science, Vol. XXV, p. 161, native lead occurring on galena, from the Jay Gould mine, Wood River district, Idaho Territory. A specimen of this occurrence in the collection of the Survey shows metallic lead, without any galena, running through a mass of quartz rock (the latter stained reddish, perhaps from minium). The quartz is somewhat cracked, and the several pieces are held in place by filaments of lead. A white coating of lead carbonate appears in a few small cavities. The lead is argentiferous.

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VII.—NEW MINERAL SPECIES FROM COLORADO.

By W. F. HILLEBRAND.

ZUNYITE.

The Zufii mine on Anvil Mountain, near Silverton, San Juan County, Colorado, has furnished to science two new minerals, one of them being of a remarkably interesting nature.

A portion of the ore from this mine, as represented by two specimens, for the use of which I am indebted to Mr. Franklin Guiterman, consists, when unaltered, of an uncrystallized sulphide of lead and arsenic, upon broken surfaces of which appear numberless projecting glassy faces of tetrahedra of the regular system. On destroying the sulphide by nitric or nitro-hydrochloric acid, washing thoroughly by decantation, and finally employing a solution of high specific gravity to effect separation from a very small amount of barite and whatever other lighter or heavier impurities may be present, a product is obtained consisting of fine crystals on which the predominant form is $\frac{0}{2}$, generally modified by $-\frac{0}{2}$, and frequently also by $\alpha 0 \infty$ and $\frac{m0m}{2}$ (Whitman Cross). While goniometric measurements of the tetrahedral angles by Mr. Cross varied frequently within a degree from the normal, this must have been owing to surface irregularities, for generally the crystals are entirely without action on polarized light, and can therefore belong to none but the regular system, although a few show very faint polarization due to interior tension (Cross).

Their size varies from that of extreme minuteness to a diameter, in rare instances, of 5 millimeters. The smallest of the crystals are generally quite clear and transparent, but the vast majority carry more or less uncrystallized, unmagnetic, black inclusions, the nature of which the microscope does not reveal. Repeated preliminary tests showed that these were in no respect similar to the sulphide in which the crystals had been imbedded, being practically insoluble in the strongest acids, with the exception of hydrofluoric acid. The tetrahedra themselves, even in fine powder, are also unaffected by any acids other than hydrofluoric, and even with this acid the action is very slow. Fusion with potassium hydrosulphate effects decomposition in time, and with alkaline carbonates quite readily.

The lustre is glassy, cleavage octahedral, hardness about 7, and the specific gravity in the case of two different lots, carrying in so far as could be judged the same amount of inclusions, was 2.906 and 2.894, at $18\frac{1}{2}^{\circ}$ C. and 20° C., respectively. By diluting a portion of the Thoulet

solution until a few minute crystals free from black specks remained suspended in the liquid, and then taking the density of the latter by a Mohr balance, the specific gravity of the pure mineral was found to be 2.875 at 15° C.

The influence of the inclusions upon the specific gravity was not sufficient to allow of effecting anything like a complete separation, by the employment of a solution of high density, of pure matter from that carrying inclusions, even when finely powdered. For although the portions first falling consisted of the largest and blackest crystals or fragments, and each succeeding precipitate was of a slightly lighter shade, the last was still noticeably dark and by no means pure. The difficulty of separation in this manner was further enhanced by the fact that much of the material from which the portions taken for final analysis were obtained was more or less altered and consequently of lower specific gravity, the result being that the pure crystals and slightly altered ones containing many inclusions fell together. After very great labor, however, enough material for final tests was obtained by hand-picking under the loupe. This showed no signs of alteration and but here and there a minute black speck.

Qualitative analysis of less pure material showed the presence of silica, titanite oxide, alumina, ferric oxide, soda, potassa, lithia, fluorine, chlorine, phosphorus pentoxide, and water. When heated in a tube acid water which attacked glass was given off. Whole crystals when heated sometimes decrepitated, and always became opaque and porcelain-like, but showed no sign of fusion in the hottest blow-pipe flame.

On account of the hardness, which rendered grinding in an agate mortar inadvisable, the sample was crushed in a steel mortar, the metal from the latter extracted by hydrochloric acid, and, after washing thoroughly by filtration, the finest portions were separated from the coarse by levigating with water. The most impalpable powder was reserved for alkali tests.

In these, decomposition was effected by igniting with three parts of bismuth oxide for half an hour at a dull red heat. Treatment with hydrofluoric acid would have required several days for the decomposition alone, and it is improbable that the Lawrence Smith method would have succeeded well. Lithia could not be quantitatively estimated, although the spectroscopic evidence of its presence was strong.

Silica, alumina, ferric oxide, titanite oxide, and fluorine were generally estimated in the same portion, and, in one instance, also chlorine and phosphorus pentoxide. Fusion was made with potassium carbonate. After separation of silica, alumina, etc., in the usual manner, the phosphoric acid remaining in solution was removed by silver nitrate. The fluorine was not calculated from the weight of calcium fluoride obtained, but from the difference between this weight and that after conversion into sulphate. In one instance (analysis LV, below) a considerable amount of pure silica was added before fusion with alkaline carbonate,

and here somewhat more fluorine was found than when no silica was added. Silica was always examined for phosphoric as well as for titanitic acid when the latter was known to be present.

The solution containing ferric (titanic) and phosphoric oxides and alumina was divided into two parts, in the one of which the phosphorus was determined, in the other the weight of the combined oxides. The latter were brought into solution by fusion with potassium hydrosulphate; the titanitic oxide if present was then thrown down by boiling in presence of sulphurous acid, and the iron was precipitated as sulphide from a tartaric acid solution and subsequently weighed as oxide. The alumina was found by difference.

Beryllia was carefully tested for by digesting the alumina and ferric oxide (introduced as chlorides) for several days with ammonium carbonate in excess. The very slight amount of matter found then in solution proved to be alumina.

Chlorine was estimated in a separate portion by precipitating as silver chloride in a platinum dish, after leaching the alkaline carbonate fusion and acidifying the filtrate with nitric acid. As a precautionary measure the chloride was then dissolved on the filter with ammonia and reprecipitated by nitric acid, after which it was collected and weighed in a Gooch crucible. In one instance the silver chloride thrown down before precipitating the fluorine as calcium fluoride was weighed and found to tally very closely with the results obtained on separate portions.

Water was estimated by heating the mineral with dry sodium carbonate in a glass tube and collecting in a weighed calcium chloride tube.

The results upon the purest material were as follows:

- LIII.—0.9055 gram gave 0.2200 SiO_2 , 0.0018 Fe_2O_3 , 0.5230 Al_2O_3 , and 0.0466 F.
 LIV.—1.1563 gram gave 0.2817 SiO_2 , 0.0022 Fe_2O_3 , 0.6710 Al_2O_3 and 0.0613 F.
 LV.—0.8436 gram gave 0.4882 Al_2O_3 , 0.0018 Fe_2O_3 , 0.0054 P_2O_5 , 0.0244 Cl and 0.0473 F.
 LVI.—0.6512 gram gave 0.0038 $\text{Al}_2\text{Si}_2\text{O}_7$, hence 0.0037 P_2O_5 .
 LVII.—1.0039 gram gave 0.0060 KCl, NaCl and trace LiCl, 0.0052 K_2PtCl_6 , whence 0.0016 KCl and 0.0044 NaCl, LiCl, or 0.0010 K_2O and 0.0023 Na_2O , Li_2O .
 LVIII.—1.0042 gram gave 0.0064 KCl, NaCl, LiCl, 0.0052 K_2PtCl_6 , whence 0.0016 KCl and 0.0048 NaCl, LiCl, or 0.0010 K_2O and 0.0025 Na_2O , Li_2O .
 LIX.—0.7022 gram gave 0.0824 AgCl, whence 0.0204 Cl.
 LX.—0.7505 gram gave 0.0891 AgCl, whence 0.0220 Cl.
 LXI.—0.5073 gram gave 0.0552 H_2O .
 LXII.—0.4021 gram gave 0.0439 H_2O .
 LXIII.—0.3502 gram gave 0.0381 H_2O .

	LIII.	LIV.	LV.	LVI.	LVII.	LVIII.	LIX.	LX.	LXI.	LXII.	LXIII.	Mean.
SiO_2	24.30	24.36	.....	.....	.....	.....	.....	.....	.....	.....	.....	24.33
Fe_2O_3	0.20	0.20	0.21	.....	.....	.....	.....	.....	.....	.....	.....	0.20
Al_2O_3	57.76	58.00	57.87	.....	.....	.....	.....	.....	.....	.....	.....	57.88
K_2O} .....	.....	.....	.....	.....	0.10	0.10	.....	.....	.....	.....	.....	0.10
Na_2O} .....	.....	.....	.....	.....	0.23	0.25	.....	.....	.....	.....	.....	0.24
Li_2O} .....	.....	.....	.....	.....	trace.	trace.	.....	.....	.....	.....	.....	trace.
H_2O} .....	.....	.....	.....	.....	.....	.....	.....	.....	10.88	10.92	10.88	10.89
P_2O_5 .....	.....	.....	0.64	0.57	.....	.....	.....	.....	.....	.....	.....	0.60
F	5.15	5.30	5.61	.....	.....	.....	.....	.....	.....	.....	.....	*5.61
Cl .....	.....	.....	2.89	.....	.....	.....	2.90	2.98	.....	.....	.....	2.91

Less O for F and Cl

102.76
3.02

99.74

* The highest figure for fluorine is here taken as probably nearer correct than the others, because of a possible analytical error in the latter having in this case been lessened by the addition of silica before making the alkaline fusion.

In deducing a formula from these data the Fe_2O_3 and P_2O_5 may for reasons subsequently mentioned be neglected. Since none of the water escapes at 270°C , it may be assumed that it exists as water of constitution, or basic water, and it is perhaps to be reckoned with the small quantities of alkalis. The atomic ratio is then found to be:

$$(\text{H}, \text{K}, \text{Na}) : \text{Si} : (\text{Al}_2) : (\text{O}, \text{F}_2, \text{Cl}_2)$$

$$1.2208 : 0.4055 : 0.5674 : 3.1232$$

or

$$18.06 : 6.00 : 8.00 : 46.21$$

which is not far from

$$18.00 : 6.00 : 8.00 : 45.00$$

giving the formula $\text{R}_{18}\text{Si}_6(\text{Al}_2)_8(\text{O}, \text{F}_2, \text{Cl}_2)_{45}$ or $9 \text{ R}_2\text{O}, 6 \text{ SiO}_2, 8 \text{ Al}_2\text{O}_3$, with part of the oxygen replaced by fluorine and chlorine.

The Fe_2O_3 of the above analyses came undoubtedly from a thin film of ferric oxide on the tetrahedral crystals which had not been entirely removed by the various treatments with acids to which they had been subjected.

The P_2O_5 cannot well be a constituent of the tetrahedra and is probably derived from a small proportion of an admixed aluminium phosphate. The excess of alumina constantly found over that required for the above formula renders this the more likely. Evidence of the presence of an admixed phosphate was also obtained by direct experiment. In material not specially purified there were observed a few irregular and generally dull grains which at first were supposed to be fragments of tetrahedra, perhaps slightly altered. Half a dozen of these, weighing in all less than 1 milligram, were picked out, crushed, fused with sodium carbonate, the fusion dissolved in nitric acid, and a few drops of molybdate solution added. A distinct yellow precipitate formed in a short time. Yet while the presence of an aluminium phosphate would, by lowering the aluminium of the above analyses, make the ratio $\text{Si}:\text{Al}$, nearer 6:8 than it has been shown to be, I am not at all certain that the discrepancy is hereby entirely to be explained. For the given amount of SiO_2 , only 55.19 per cent. of Al_2O_3 is required, leaving 2.69 per cent. for combination with only 0.60 per cent. of P_2O_5 . Moreover, the above given ratio between SiO_2 and Al_2O_3 has been found by repeated careful analyses not included in the above, made on entirely different samples, to be practically constant. It is therefore possible that the true formula is more complex than that given above, or that some source of contamination exists which has as yet escaped detection.⁶¹

⁶¹After the above was ready for the press Mr. Cross communicated to me the following facts as the results of further microscopical examination:

"The zunyite has a polarizing inclusion, quite plentiful in a few crystals, but lacking entirely in most of them. When mounted in balsam the dark impurities stand out very plainly, causing the crystals to seem much more impure than they really are. The polarizing substance cannot be identified, but it is too brilliant for apatite. It has no good crystal form." This polarization, he further says, is distinct from that mentioned on p. 100, as occasionally shown by the zunyite itself. Hereby the opinion expressed above, that some foreign admixture was present, is confirmed.

As a name for the mineral, *Zunyite* is proposed, after the mine from which it was obtained.

The black inclusions in the zunyite were shown to contain titanic oxide by the following partial analyses of dark crystals:

SiO ₂	23.98	23.98
TiO ₂	0.75	0.84
Al ₂ O ₃	*58.30	*58.45

*Not freed from Fe₂O₃ and P₂O₅.

In order to ascertain whether they consisted only of titanic oxide or of some titanate, an attempt was made to separate from the zunyite a quantity sufficient for analysis. It was soon found that this could be but very imperfectly accomplished and only by reducing large quantities of zunyite crystals to fine powder and then effecting the separation by means of the Thoulet solution. In this manner a mixture of barite, black particles, and attached zunyite was obtained, weighing, after thorough washing, but 0.5528 gram, which furnished the following results on analysis:

	LXIV.
BaSO ₄	88.90
SiO ₂	1.50
TiO ₂	8.60
Al ₂ O ₃	8.88
Fe ₂ O ₃	0.20
P ₂ O ₅	Trace.
H ₂ O, F, Cl, and loss	2.47
	100.00

Since the silica and alumina bear to each other nearly the same ratio as in zunyite, and since both fluorine and water were found to be present in small quantity, it is probable that all these were derived from attached zunyite, the perfect separation of which from the inclusions is practically impossible even with the comparatively large amounts operated upon. There remains then only titanic and a little ferric oxide, showing that the inclusions consist, in all probability, of titanic oxide alone.

By far the greater part of the zunyite-bearing ore seems to be in an advanced stage of decomposition. Through the kindness of Mr. J. A. Porter, of Durango, Colorado, the Colorado Scientific Society is the possessor of about fifty pounds of this altered ore completely filled with zunyite. The original double sulphide has almost disappeared, being changed into lead sulphate and other less well-defined compounds. While the zunyite is here in great measure still perfectly fresh, a considerable portion has been more or less altered, incipient change being indicated by a faint cloudiness through the crystals which, beginning apparently at the centre, spreads outward and increases in degree until, as a final product, there ensues a dull white opaque substance retaining in a measure the outlines of the original crystal and showing here and there a black grain of titanic oxide.

It was from this partially-altered ore that the material for the complete analysis above given and for the investigation of the inclusions was obtained, as the specimens of unaltered sulphide were too small to afford sufficient material by hand-picking.

A knowledge of the composition of the result of alteration of zunyite seemed desirable; hence the lightest of all portions separated by the Thoulet solution, of specific gravity 2.45, was partially analyzed. The result was unsatisfactory, indicating a mixture of probably several substances, of which a little undecomposed zunyite is known to be one, but the general character of the chemical change is in a measure shown.

	LXV.
SiO ₂	58.47
Al ₂ O ₃	22.08
Fe ₂ O ₃	0.27
CaO(SrO)	1.70
ZnO	0.20
K ₂ O	0.58
Na ₂ O(Li ₂ O)	1.29
P ₂ O ₅	2.21
As ₂ O ₃	0.40
SO ₂	4.52
F	0.91
Cl	0.15
H ₂ O and loss	9.32
	100.00

Some of the constituents, as the As₂O₃ and ZnO, have evidently been derived from the sulphide ore in which the mineral was imbedded.

GUTTERMANITE.

The metallic sulphide forming the matrix of the zunyite, of which in a fresh state, as before observed, but two specimens were at disposal, is of a bluish-gray color, possesses light metallic lustre, and a hardness of about 3 on places free from included zunyite. A small amount of pyrite is visible in spots.

Heated in the closed tube it fuses readily and there appears a slight sublimate of sulphur followed by a heavy one of arsenic sulphide; while on charcoal the usual reactions for sulphur, arsenic, and lead may be observed.

The following analyses were made:

	LXVI.			LXVII.		
	a.	b.	Mean.	a.	b.	Mean.
Zunyite	1.77	1.77	1.77	8.81	8.82	8.82
As	13.50	13.80	13.40	13.00	13.00	13.00
Pb	63.40	63.80	63.60	61.65	61.62	61.63
Cu	0.17	0.18	0.17	0.17	0.17	0.17
Ag	0.02	0.02	0.02	0.02	0.02	0.02
Fe	0.42	0.43	0.43	0.87	0.89	0.88
S	19.65	19.70	19.67	19.67	19.45	19.56
O				0.55		0.55
Total	98.93		99.06	99.74		99.63

Analyses LXVI *a* and *b* were first made, on material which had a specific gravity of 5.828 at 17½° C. Corrected for admixed zunyite of specific gravity 2.9, this becomes 5.94. As the total could hardly be brought above 99 per cent., in spite of great care in analyzing, the cause of this was sought for and found as will be subsequently explained.

In the experiments (not of a quantitative nature) having this end in view the sample was exhausted, therefore fresh material was used for two subsequent analyses, LXVII *a* and *b*.

In both these and the previous ones the sulphur was found in excess of that required for the metals, on the assumption that all the arsenic was present as trisulphide and the iron as disulphide. This was due to the presence of free sulphur, which was estimated quantitatively by extracting with carbon disulphide and carefully evaporating the filtrate to dryness in a weighed crucible. After three extractions no more sulphur was dissolved. The amount thus obtained represented 0.59 per cent. of the material used for analyses, LXVII, *a* and *b*.

While accounting completely and satisfactorily for the excess of sulphur, this did not explain the low summation shown in the first analyses. It was found, however, that notwithstanding the apparent purity of the mineral, lead sulphate was present in some quantity.

The sulphur trioxide of this was estimated by extracting the sulphate from the mineral by digestion with warm dilute hydrochloric acid in an atmosphere of carbonic acid, three or four digestions being sufficient for complete extraction, and, after partial neutralization of the filtrate, precipitating as barium sulphate. The result was 0.69 per cent. SO₃. The lead oxide of the sulphate could not be estimated in this extract, because even the dilute acid slightly decomposed the sulphide, taking lead but no arsenic into solution. Under the conditions of the experiment practically no hydrogen-sulphide could be oxidized in the short time required for making the extraction.

As a check, the lead oxide of the sulphate was estimated quantitatively by extracting the sulphate with neutral ammonium acetate in a closed flask, three or four digestions with fresh solution being sufficient, throwing down the lead as sulphide, and converting into sulphate before weighing. The percentage of lead oxide thus found was 2.70, instead 2.61 required by the 0.69 of SO₃ found. 2.61 of PbSO₄ contains 1.78 of lead, 0.28 of sulphur, and 0.55 of oxygen. Thus the sum total was brought much nearer to 100.

Excluding now the lead sulphate, free sulphur, and pyrite, the following atomic values are obtained:

Pb.....	59.85 ÷ 207. = 0.2891	} 0.2904	3.35	10.05
Cu ₂	0.17 ÷ 126.8 = 0.0013			
As ₂	13.00 ÷ 150. = 0.0866			
S	17.68 ÷ 32. = 0.5525			
			1.00	3.00
			6.38	19.14

These lead to the formula 10 PbS, 3 As₂S₃. A simpler formula, and one not far removed from the above, is 3PbS, As₂S₃. If a small quan-

tity of galena was present, of which, however, there was no evidence, other than that afforded by the decomposition of some lead sulphide by dilute hydrochloric acid without simultaneous solution of arsenic, the latter formula is probably the correct one. But this evidence is of little value, for any arsenic dissolved from the double sulphide would probably be immediately thrown down again by the hydrogen sulphide evolved. Whichever formula may be the true one, the mineral appears to be new to science, and a name, *Guitermanite*, is proposed, in honor of Mr. Franklin Guiterman, who first called attention to this and the associated zunyite.

In conclusion, a few words will be in place respecting the occurrence of these two new minerals. According to Mr. Guiterman there appears to be no decided indication of a fissure vein in the Zuñi mine, but the minerals occur in what seem to be pipe veins enlarged in places, the surrounding rock being probably andesite. In this and other mines of the region kaolinization of the country rock is a marked feature.

A PROBABLY NEW MINERAL.

A portion of the ore from the Missouri mine, Hall's Valley, Park County, Colorado, is composed largely of a sulpho-bismuthide of copper and silver. It occurs in a quartz gangue associated with chalcopyrite and wolframite, and although the latter is only visible on close examination, it comprises from 1 to 2 per cent. of the whole, as found by special tests. A considerable quantity was extracted by chemical and mechanical means, free from all foreign matter except a little attached quartz, and was proven to be wolframite by qualitative chemical tests and by a determination of the specific gravity.

The mass of the sulpho-bismuthide appears throughout the quartz as a dark, bluish-gray substance without distinct forms of crystallization. In numerous cavities appear small slender crystals, generally bronzed by oxidation and so deeply striated as sometimes to present the appearance under the loupe of bunches of needles. Occasionally they seem to be joined together laterally forming thin corrugated plates. Owing to this deep striation no crystal faces can be detected either on the sides or the free terminations. The habit is strikingly like that of bismuthinite, for which the crystals were, indeed, at first taken.

After several days labor enough material was removed from the cavities for the determination of the metals. It could not, however, be freed altogether from quartz and chalcopyrite. The specific gravity at 17° C. was 5.75. Making correction for 4.43 per cent. of quartz and 6.98 per cent. of chalcopyrite of assumed specific gravities 2.65 and 4.2, this becomes 6.31. The analysis appears under LXVIII below.

The more compact material, excluding as far as possible the needles, gave, after deducting 59.75 per cent. of gangue, the results under LXIX.

LXX is the analysis of a mineral presented by Mr. William McCree as coming probably from the Missouri mine. In appearance it differs in no respect from the compact material already described, except that no chalcopryite is distinctly visible in the small specimens at my disposal, and the quartz grains are less firmly cemented together. It contains, however, some lead, which is entirely wanting in the other specimens analyzed, although the general formula is the same; hence I am led to believe that it came from some other portion of the workings or from an adjacent mine where ore like that from the Missouri mine is reported to occur. The specific gravity was 3,869 at 15° C., which becomes 6.680 on making correction for 47.57 per cent. of gangue of ascertained specific gravity 2.643.

The most marked blow-pipe reactions for LXVIII, LXIX, and LXX, were entirely similar, a sublimate of sulphur appearing in the closed tube, sulphur dioxide escaping in the open tube, and the fused fragment or powder on charcoal affording the bismuth reactions with great intensity. All were soluble in nitric and hydrochloric acids, in the latter with precipitation of silver chloride.

	LXVIII.	LXIX.	LXX.
Bi	60.74	68.86	62.45
Ag	0.80	4.00	3.89
Cu	15.96	12.65	6.68
Pb			2.74
Fe	2.13	0.50	0.10
Zn	0.10	0.07	0.07
S	*19.94	*18.83	17.90
	99.76	99.59	99.83

*Calculated.

After subtracting from LXVIII 6.97 per cent.; from LXIX, 1.91 per cent., and from LXX, 0.33 per cent. of chalcopryite, with the proportions of sphalerite represented by the zinc, the atomic ratios become:

	R	:	Bi ₂	:	S.
LXVIII.	3.00	:	3.95	:	14.75.
LXIX.	3.00	:	4.03	:	14.98.
LXX.	3.00	:	4.10	:	15.15.

where R represents Pb and the double atoms Ag₂ and Cu₂. In each case the ratio is nearly 3:4:15, which leads to the general formula 3RS + 4Bi₂S₃.

It seems probable that the needle-like crystals are a pure sulphobismuthide of copper, and that in the more compact portions silver replaces a part of the copper, and in some cases a further replacement of copper by lead takes place.

This ore from the Missouri mine is auriferous. The material used for analysis LXIX, gangue and sulphide together, assayed 1.85 ounces gold to the ton. According to Mr. Pearce, of the Boston and Colorado Smelting Works, it was frequently much richer, running as high as 40 ounces to the ton.

Before conferring a name upon this mineral, or even definitely claiming it as a new species, further investigation is advisable. A personal visit to the Missouri and other neighboring mines in October, 1884, in the hope of obtaining better material, was not rewarded with success.

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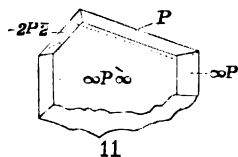
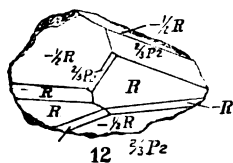
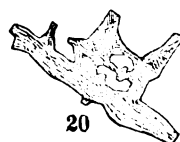
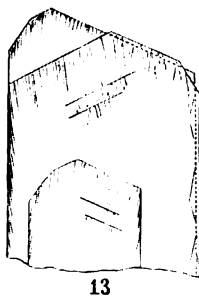
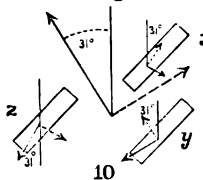
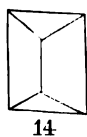
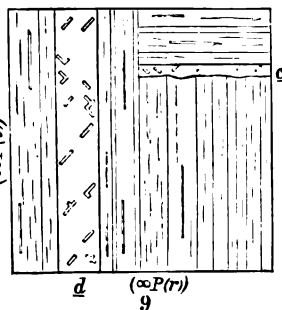
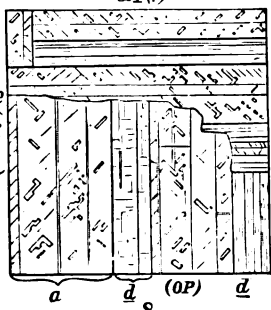
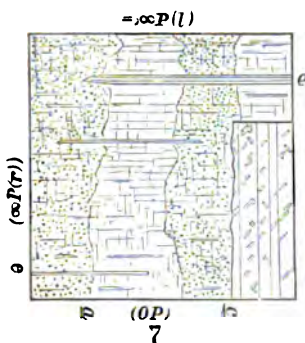
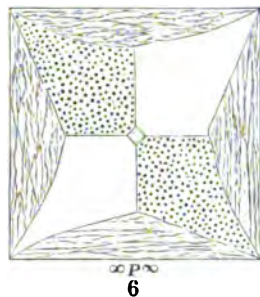
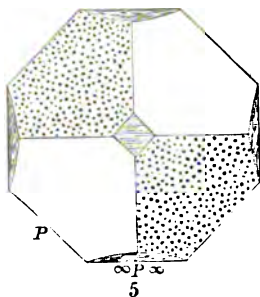
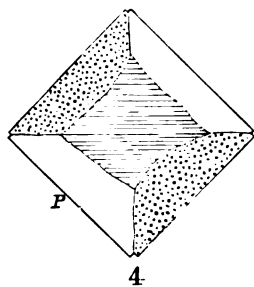
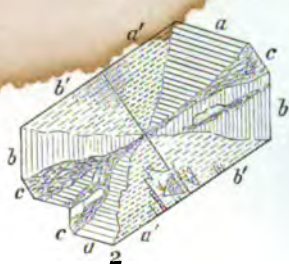
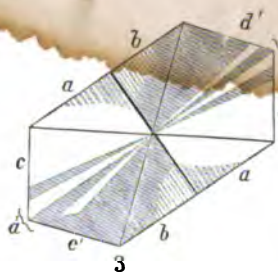
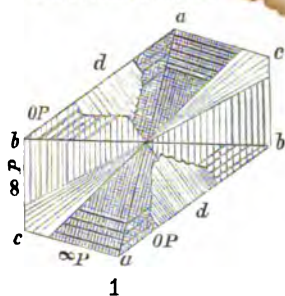
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EXPLANATION OF PLATE.

- Fig. 1 illustrates the twin structure and optical properties of stilbite, seen in clinopinacoidal section, as described by von Lasaulx. See text, p. 20.
- Fig. 2 illustrates the twin structure and optical properties of stilbite from Table Mountain, in corresponding position to that of Fig. 1. See text, p. 21.
- Fig. 3 illustrates the twin structure and optical properties of phillipsite, as described by Trippke. See text, p. 23.
- Figs. 4, 5, and 6 show the optical anomalies observed in the apophyllite of Table Mountain, by C. Klein. See text, p. 30.
- Figs. 7, 8, 9, and 10 illustrate the polysynthetic twin structure observed in the cryolite of Saint Peter's Dome. See text, pp. 43-47.
- Fig. 11 represents the crystal form of prosopite from Saint Peter's Dome. See text, p. 63.
- Fig. 12 represents a crystal of phenacite from Crystal Park, natural size. See text, p. 68.
- Fig. 13 shows the position of the parting which produces the lustre of the sanidine in the nevadite of Chalk Mountain. See text, p. 76.
- Fig. 14 the fundamental form of löllingite. See text, p. 90.
- Figs. 15 and 16, forms of löllingite, observed in the material from Gunnison County, Colorado. See text, p. 90-91.
- Figs. 17, 18, 19, 20, and 21 represent different forms of a rhombic arsenide of iron, cobalt, and nickel, observed in association with löllingite, Gunnison County, Colorado. See text, p. 91.



NOTICE.

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